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DEPARTMENT OF PHYSICS
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

TECHNICAL REPORT PTR-84-3

NASA THREE-LASER AIRBORNE DIFFERENTIAL
ABSORPTION LIDAR SYSTEM ELECTRONICS

By

Robert J. Allen

and

Gary E. Copeland, Principal Investigator

Final Report

For the period December 15, 1979 to December 31, 1984

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Under
Cooperative Agreement NCC1-32
E.V. Browell, Technical Monitor
ASD-Chemistry and Dynamics Branch

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Submitted by the
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NASA THREE-LASER AIRBORNE DIFFERENTIAL ABSORPTION LIDAR SYSTEM ELECTRONICS

By

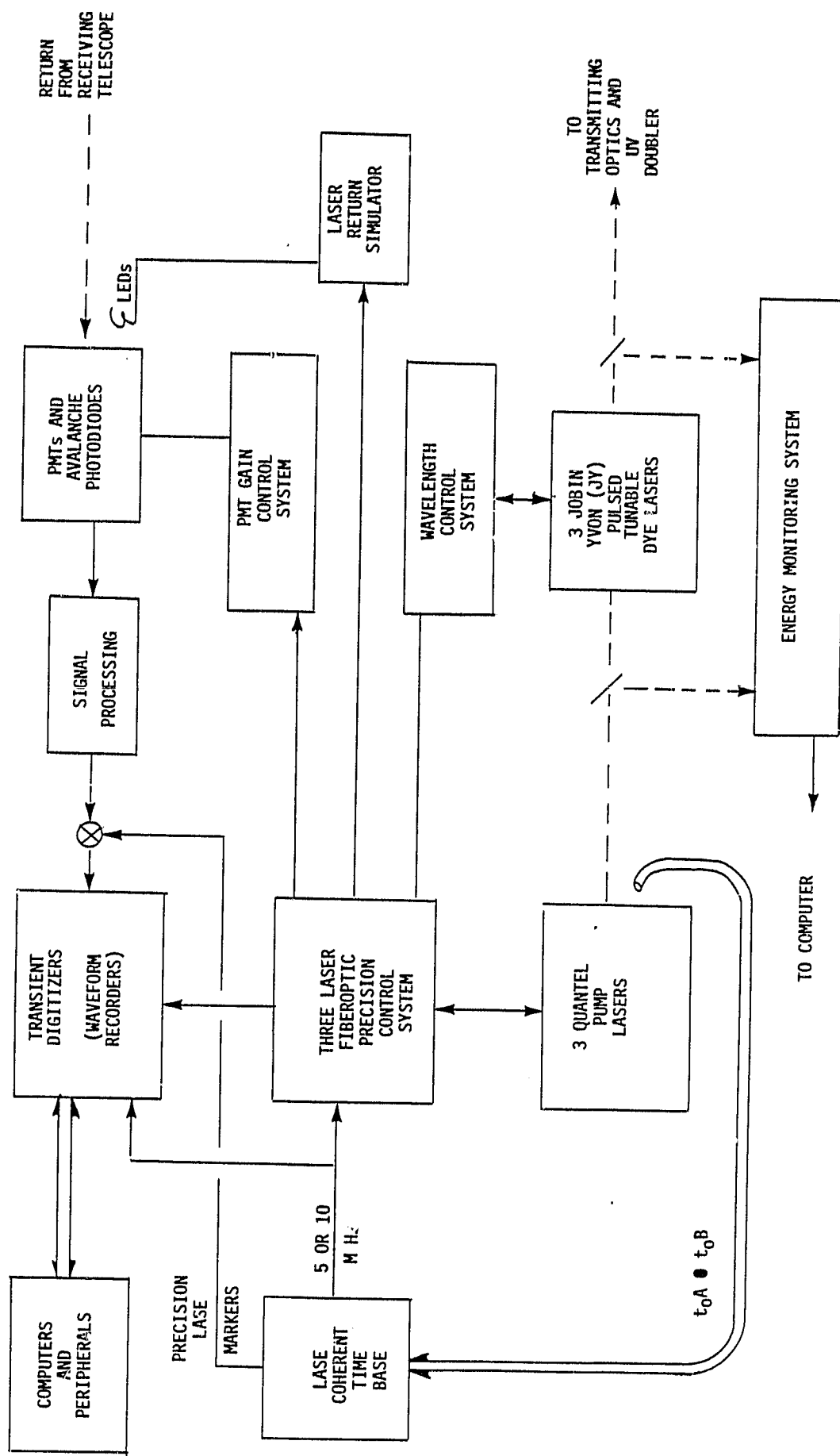
Robert J. Allen¹ and Gary E. Copeland²

INTRODUCTION

This report describes the NASA three-laser airborne differential absorption lidar (DIAL) system control and signal conditioning electronics. The lasers, optics development and central computing system are discussed elsewhere (refs. 1-3). Photomultiplier network analysis will be reported later after further progress is made in this area. This multipurpose DIAL system has been developed for the remote measurement of gas and aerosol profiles in the troposphere and lower stratosphere. It can operate from 280 to 1064 nm for the remote measurements of ozone, sulfur dioxide, nitrogen dioxide, water vapor, temperature, pressure, and aerosol backscattering. The complete system is shown in Figure 1 and consists of: (A) a Lase Coherent Time Base, (B) the Precision Control System described in the body of this report, (C) up to three Quantel 1064/532 nm pump lasers, (D) up to three Jobin Yvon (JY) dye lasers, (E) a wavelength control system consisting of a French (CNRS) designed wavelength control unit and a NASA designed synchronizing (interface) unit, (F) an Energy Monitoring System, (G) transmitting and receiving optics, (H) PMTs and an Avalanche Photodiode, (I) up to three PMT Step and function Gain Control Systems, (J) Signal Processing Units, (K) up to four Transient Digitizers (waveform recorders), (L) a Computer System and associated software, and (M) a three-channel Laser Return Simulator. A brief description and photographs of the majority of

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electronics units developed under this contract are presented in the appendix, and a detailed description and photographs of the remainder of the units associated with the Control System are contained in the main body of this report.

The Precision Control System described in the subsequent section of this report includes a Master Control Unit, three combined NASA Laser Control Interface/Quantel Control Units, and three Noise Pulse Discriminator/Pockels Cell Pulser Units. This system is designed to operate within a high EMI* environment using high speed electro-optic transmitters/receivers coupled with fiber optics to carry the control signals between units. It can provide: (1) precision timing (to within 24 ns) for sequential or alternate control of up to three pump lasers driving three dye lasers, (2) control of up to three PMT gain function generators, (3) synchronization of the wavelength control system, (4) arming and triggering of the transient digitizers, and (5) control of up to three Laser Return Simulator signals coordinated with preventing the pump lasers from firing (primarily for automatic inflight calibration purposes). The only input to the Precision Control System is a 5 or 10 MHz square wave used as a system time base. The need and design considerations for precision timing and control are first discussed followed by the Theory of Operation of the complete Control System and each of the units. Calibration procedures are included to allow this document to be used as a reference in support of this Multicolor Lidar Research Project.

*Electromagnetic interference (EMI) is produced as the result of switching high voltages associated with the Quantel laser system flashlamps and Pockels cell. A 15,000 volt 2-microsecond pulse is used to reionize the flashlamps producing a severe noise problem. Fiber optic links, extra shielding, filtering, careful grounding, gating techniques, and the use of digital logic with high noise immunity were incorporated to minimize the effects of this HV switching. EMI problems are considerably reduced when laser systems use flashlamp dimmer supplies.

NEED FOR PRECISION TIMING AND CONTROL

Differential Absorption Lidar Systems profile gas concentrations by transmitting energy into the atmosphere at two different wavelengths: one corresponding to an absorption line of gas species to be profiled -- called the ON-LINE observation -- and a second wavelength that is not being absorbed (at least to the extent of the on-line wavelength) by the gas species -- the OFF-LINE observation. NASA Langley Research Center has selected an approach where the on-line laser transmits first at a wavelength ON the absorption line followed 100 microseconds later* by the second laser transmitting at the OFF wavelength. This period is short enough to minimize changes in observed atmospheric volumes even when probing from an aircraft platform. The on-line laser was selected to transmit first since its return is weaker than the off-line and thereby will minimize multiple-go-around interference when firing upwards.

A single detector assembly (PMT or Avalanche Photodiode) coupled to a single transient digitizer processes the on- and off-line signals sequentially. Using a single channel as opposed to separate on and off-line channels, minimizes gain non-linearity between channels and eliminates the need for special dichroic beamsplitters within the receiving optical path. When the gains $G_{\text{off}}(R1) = G_{\text{off}}(R2)$ and $G_{\text{on}}(R1) = G_{\text{on}}(R2)$, the value of the average gas concentration, N , between range $R1$ and $R2$ can be calculated from the ratio of lidar signal at the on and off wavelengths from

*50 μ s and other separations may be obtained by selecting either a 5 MHz or 10 MHz time base and resetting the Laser Firing Separation dip switches as described later.

$$N = \frac{1}{2(R_2 - R_1) (\sigma_{on} - \sigma_{off})} \ln \frac{P_{off}(R_2)P_{on}(R_1)}{P_{off}(R_1)P_{on}(R_2)} \quad (1)*$$

where $\sigma_{on} - \sigma_{off}$ is the difference between the absorption cross sections at the on and off wavelengths, and $P_{on}(R)$ and $P_{off}(R)$ are the signal powers received from range, R , at the on and off wavelengths, respectively. Errors in gas concentrations due to errors in range determinations were first indicated in analysis of atmospheric observations conducted by Drs. Ed Browell and Syed Ismail. These errors are quite evident when ozone concentrations in parts per billion (PPB) are plotted (See Figure 2) vs altitude where a large gradient in concentration occurs within a small altitude change. Fig. 2A shows the concentration for the correct phasing of the on- and off-line returns ($R1_{on} = R1_{off}$ and $R2_{on} = R2_{off}$). When the off-line return is shifted early (-50 nanoseconds) or late (+50 nanoseconds), unreal excursions are generated in the computed concentrations near the real concentration gradient (Fig. 2B). Thus, certain design considerations are important to insure that the $R1$ s and $R2$ s are equal. These will now be discussed.

*As indicated by Browell et al. (1983), this relationship assumes that the aerosol and molecular optical properties are equal at the on and off DIAL wavelengths. If there is an interfering gas which does not have the same absorption coefficient at these wavelengths, the concentration of this gas must be known or determined by a separate measurement.

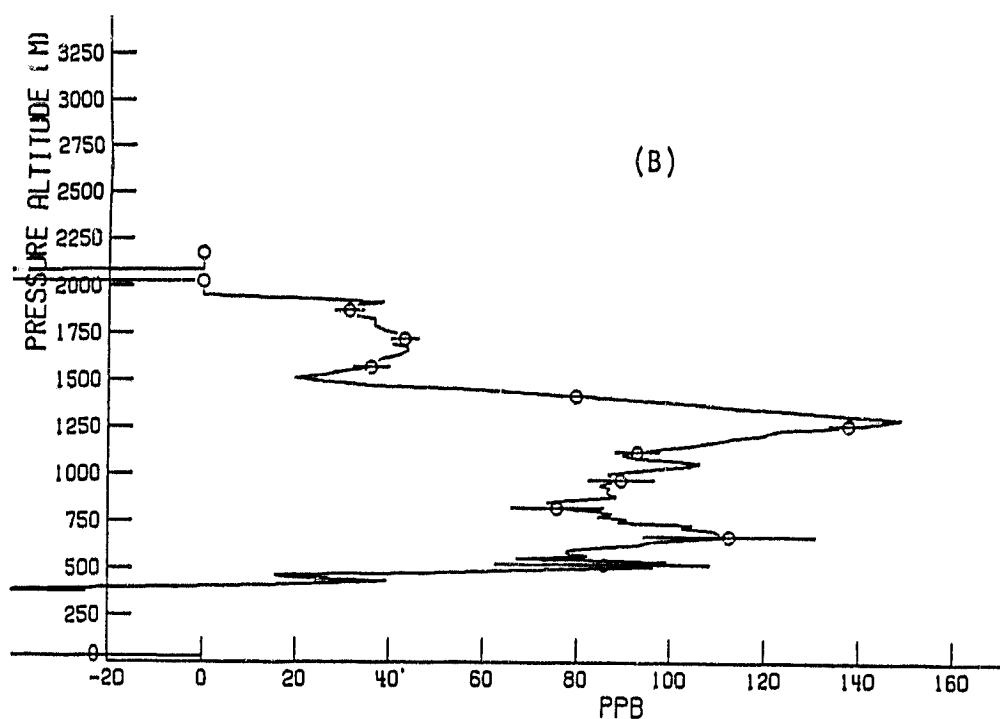
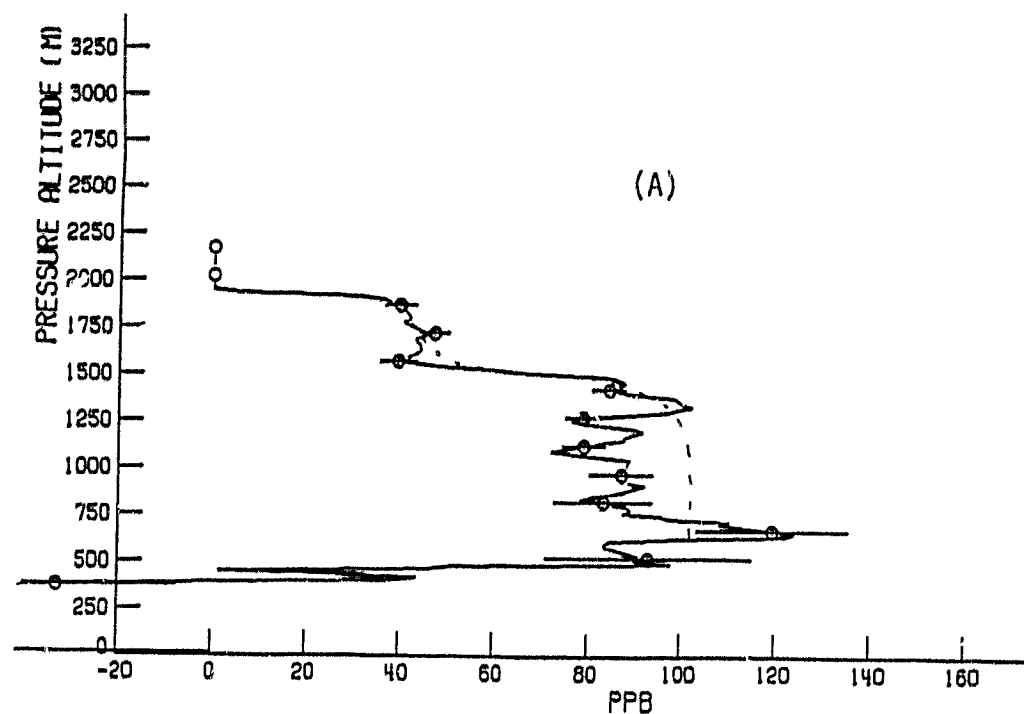


Figure 2. Computer Plot of Ozone Concentration vs Altitude (A) correct phasing of the ON and OFF-LINE returns (B) OFF-LINE return shifted 1/2 word (50 ns).

DESIGN CONSIDERATIONS TO IMPROVE PRECISION OF GAS CONCENTRATION OBSERVATIONS

As was illustrated, the highest precision is obtained when calculating gas concentration if $R1_{on} = R1_{off}$ and $R2_{on} = R2_{off}$. To insure this, precision lase markers are inserted within the analog data stream (Fig. 1) that reference the time of the on-line lase and, 100 microseconds later, the off-line lase time. These markers are derived from photodiodes sensing scattered light from the pump laser optics (routed through light pipes) and are delayed from the actual lase by the response times of the photodiodes and propagation delays within the logic circuitry. The important consideration is that these delays should be equal for the on- and off-line markers. The absolute magnitude of the delay time, if known, is less important since range differences are used in the gas concentration calculations. Amplitude saturated lase markers, two words wide when digitizing at a sample interval of $0.1 \mu s$ and one word wide at a sample interval of $0.2 \mu s$, have been selected for this application.

The precision of the time base used in the digitization process by the waveform recorder must be considered. It controls the sampling interval which is directly related to range. Changes in the time base frequency, between the times that the on- and off-line returns are received, is the main consideration. Short and long term drifts are minimized by the use of a crystal controlled time base within the Lase Coherent Time Base module.

Synchronization of the lase time (lase markers) and the time base is a major design consideration. Digitization by the transient digitizer occurs within an aperture that has a fixed relationship (with jitter) to the leading edge of the time base. If the lase time were allowed to occur anytime within the 100 ns period of the 10 MHz time base, then the range error approaches 15 meters. This produces errors in the concentration measurement

as indicated in Fig. 2.

To minimize this error, the same time base is supplied to both the Master Control Unit and the Digitizer. The first technique used was to precisely maintain the separation between the on and off-line lases. This was accomplished to within 20 ns; however, even this precision did not always insure that the lase marker would remain within the same digitizer aperture. An improved method employed was to start and stop the time base controlled by a photodiode sensing each of the actual lasings. A module was developed to accomplish this called the Lase Coherent Time Base (Appendix A) which allows the lase time and time base to be synchronized to within 4 ns. This technique practically eliminated the "word jumping" error and relaxes the need for precise control of the on and off-line separation.

The theory of operation of the Three Laser Fiberoptic Control System will now be discussed. First, the general theory of the complete Precision Control System will be presented, and then each of the subsystems will be addressed individually. The final section will include the timing calibration techniques required to optimize the energy output from each of the laser systems.

THEORY OF OPERATION

Precision Control System

The Three Laser Precision Control System provides timing and control for the firing of one, two or three Quantel Nd-YAG lasers pumping three Jobin Yvon Dye lasers, and for the recording of the atmospheric returns from the fired lasers. The System consists of (Fig. 3): (1) a Master Control Unit which generates the various Sequence Control (SC) pulses, clocks, triggers, calibration commands and laser control commands; (2) three Combined NASA Laser Control Interface/Quantel Control Units used to receive the commands, return the responses and control the lasers over fiber-optic cables; and (3) three Noise Pulse Discriminator/Pockels Cell Pulser Units with "gating" techniques to minimize noise pulses and accept the Pockels cell commands for the precise Q-switching of each of the lasers. There are two main modes for operation:

1. SEQUENTIAL MODE with the three lasers lasing, for example, at a 10 Hz rate (100 millisecond period) in sequence as follows:
 - a. Time S4--Pump laser (P1) lases to pump a dye laser which is doubled to produce an output, for example, at 285 nm (On-Line of ozone).
 - b. Time S5 (100 μ s after S4)--Pump laser (P2) lases to pump a second dye laser which is doubled to produce an output at 300 nm (On-Line of sulfur dioxide).
 - c. Time S6 (100 μ s after S5)--Pump laser (P3) lases to pump a third dye laser which is doubled to produce an output at 295 nm (Off-Line of both above gas species).
2. ALTERNATE MODE (2/1 Off to On Line). The OFF-LINE laser P3 fires, for example, at a 10 Hz rate while the other two fire at a 5 Hz rate as follows:
 - a. Time S5--Pump laser (P1) lases causing the dye laser to output at 285 nm (Ozone).
 - b. Time S6 (100 μ s after S5)--Pump laser (P3) lases causing the dye laser to output at 295 nm (OFF-LINE).

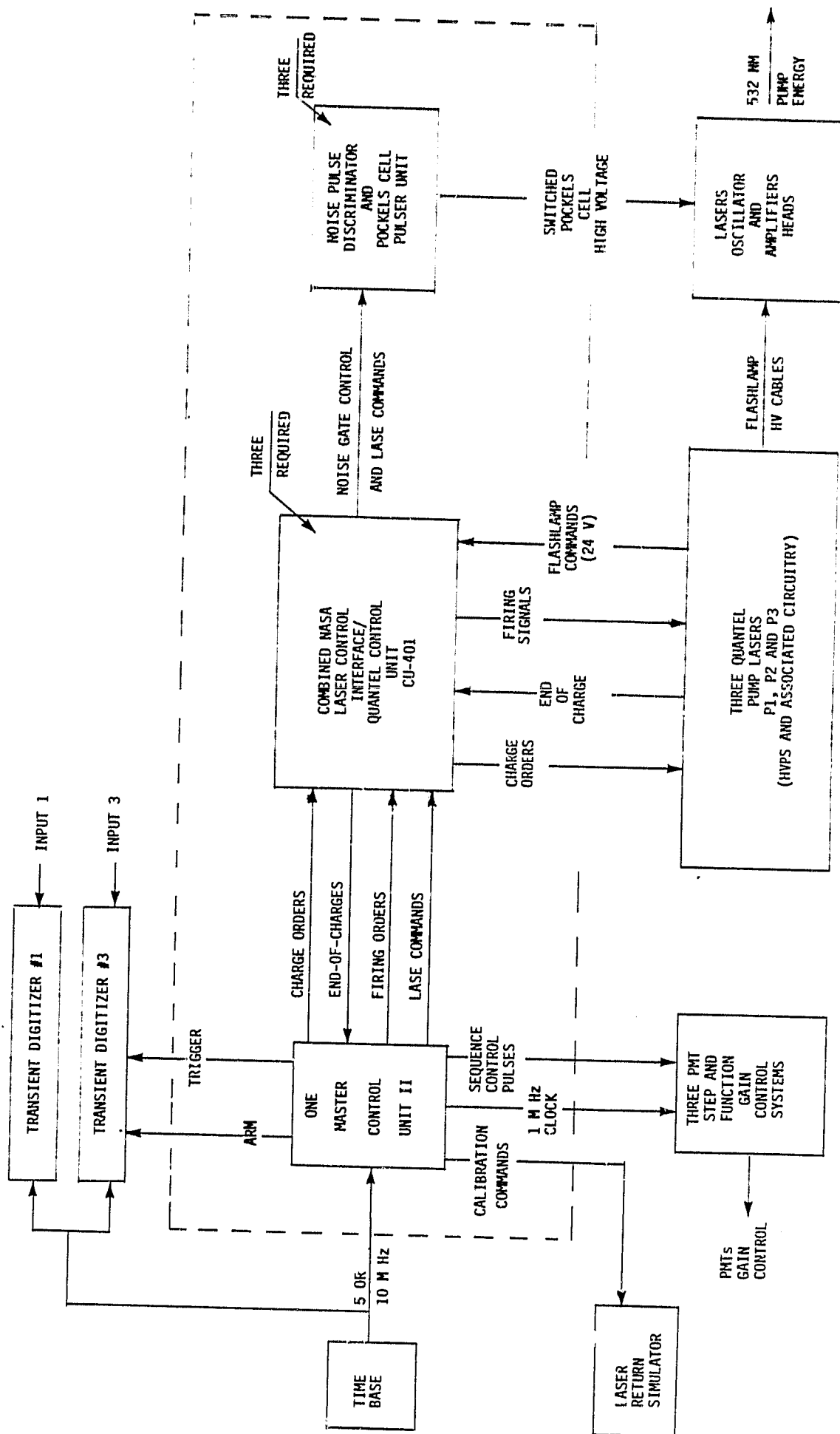


Figure 3. General Block Diagram, Three Laser Fiberoptic Precision Control System.

- c. Time S5 (following sequence 100 ms later)--Pump laser (P2) lases causing the dye laser to output at 300 nm (sulfur dioxide).
- d. Time S6 (100 μ s after S5)--Pump laser (P3) again lases causing the dye laser to output at 295 nm (OFF-LINE).

(The off-line laser, P3, lases each time whereas the on-line lasers, P1 and P2, lase alternately every other time).

A summary description of the system operation can best be visualized by referring to the block diagram, Fig. 3. A single oscillator provides a selectable 10 MHz or 5 MHz time base to the Master Control Unit II, and through matched cables to the transient digitizers (Biomation 1010's or Transaics 2012). This time base synchronizes the total system operation and is divided down to produce Charge Orders at a selectable rate via the Combined Laser Control Interface/Quantel Control Unit to the selected Quantel pump lasers. After the capacitor banks have been fully charged (nominally less than 98 ms at 10 Hz with a "hard" primary power bus), each pump laser returns an End-of-Charge signal to the Master Control Unit. This unit will then produce Firing Orders and route them to the Control Unit which will produce Firing Signals to the pump lasers. These Signals produce oscillator and amplifier flashlamp triggers that have been delayed in different amounts by separate Quantel front panel controls, thereby accounting for flashlamp aging and variances in their impedances. These two delays are adjusted to allow the oscillator and amplifier ND-YAG rods to reach maximum energy storage at approximately the same time. This will be discussed below in the section on Calibration Procedures.

The Firing Signal is also used to produce a Noise Gate which will prevent noise spikes generated by the ionization of the flashlamps from triggering the Pockels Cell. Following this, the Master Control Unit issues a Lase command that will dump the stored energy within the laser rod when this

energy reaches its peak. Coarse and Fine controls are located on the front panel of the Master Control unit and provide a means of selecting the correct Lase Command delay to optimize this timing. When a single laser is used in the Local mode, the Oscillator Flash-lamp Command (called the 24 V signal) is routed to the combined Interface/CU401 Control Unit which produces a Lase Command after a preselected delay period.

Various combinations of the Time Base frequencies, On- and Off-Line lase separations, maximum range limitations, and total number of recorded words are selectable. The sample interval of the Transient Digitizer is controlled by the external Time Base and is usually 0.1 or 0.2 μ s per sample. With a round trip light speed of 150 meters per microsecond, the maximum range possible without the danger of interference from a previous return is 7.5 km for a lase separation of 50 μ s and 15 km for a lase separation of 100 μ s. This is adequate when lasing in the down-looking mode from an aircraft flying below that altitude, but is a concern when in the up-looking mode. Some of the different combinations are listed in Table I.

Table I. Combinations of Time Base Frequencies and Transient Digitizer Sample Intervals, 3 Lasers Firing

MASTER CONTROL			TRANSIENT DIGITIZER			
Time Base	Lase Separation*	Maximum Range	Time Base	Sample Interval	Recorded Words:	
					Alternate	Sequential
10 MHz	50 μ s	7.5 km	10 MHz	0.1 μ s	1000	1500
5 MHz	100 μ s	15 km	10 MHz	0.1 μ s	2000	----
5 MHz	100 μ s	15 km	5 MHz	0.2 μ s	1000	1500

*Other separations may be obtained by resetting the Laser Firing Separation dip switch U25 in the Master Control Unit.

Individual Units

Each of the units that comprise the Precision Control System will now be discussed.

A. Master Control Unit II

The Master Control Unit (Figs. 4A and B) is provided a selectable 5 or 10 MHz time base input from which it generates and outputs a 1 MHz clock, the various sequence control pulses (SC1 through SC8, Table A1), and the charge orders (CO1, CO2 and/or CO3) to the operating lasers. After it receives end-of-charge signals (EC1, EC2 and/or EC3) from all operating lasers, it further outputs the firing order (FO1, FO2 and FO3) and lase command (LC1, LC2, and/or LC3) pulses. When instructed by front panel switch selections or remotely by the computer, the Master Control Unit will prevent all the lasers from firing by eliminating all FO's and LC's pulses and will output calibration commands (CC) at times S4, S5 and/or S6 to the Laser Return Simulator instructing it to simulate a laser return signal. This provides a means of calibrating the end-to-end receiver functions either manually during ground operations under front panel control, or periodically during flight under computer control. In addition, the lasers can be prevented from firing by front panel or computer control without selecting the Laser Return Simulator signals in the event a "background" reading is desired. Other outputs from the Master Control Unit include an Arm command and a Trigger (at S5) for the Transient Digitizers, a selectable scope trigger, synchronization signals for the Wavelength Control System, and markers to identify which of the two ON-LINE lasers fired when in the Alternate Mode. The functions of the front panel controls are listed in Table II.

The theory of operation of the Master Control Unit can best be discuss-

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Figure 4A. Photograph of the Master Control Unit front panel.

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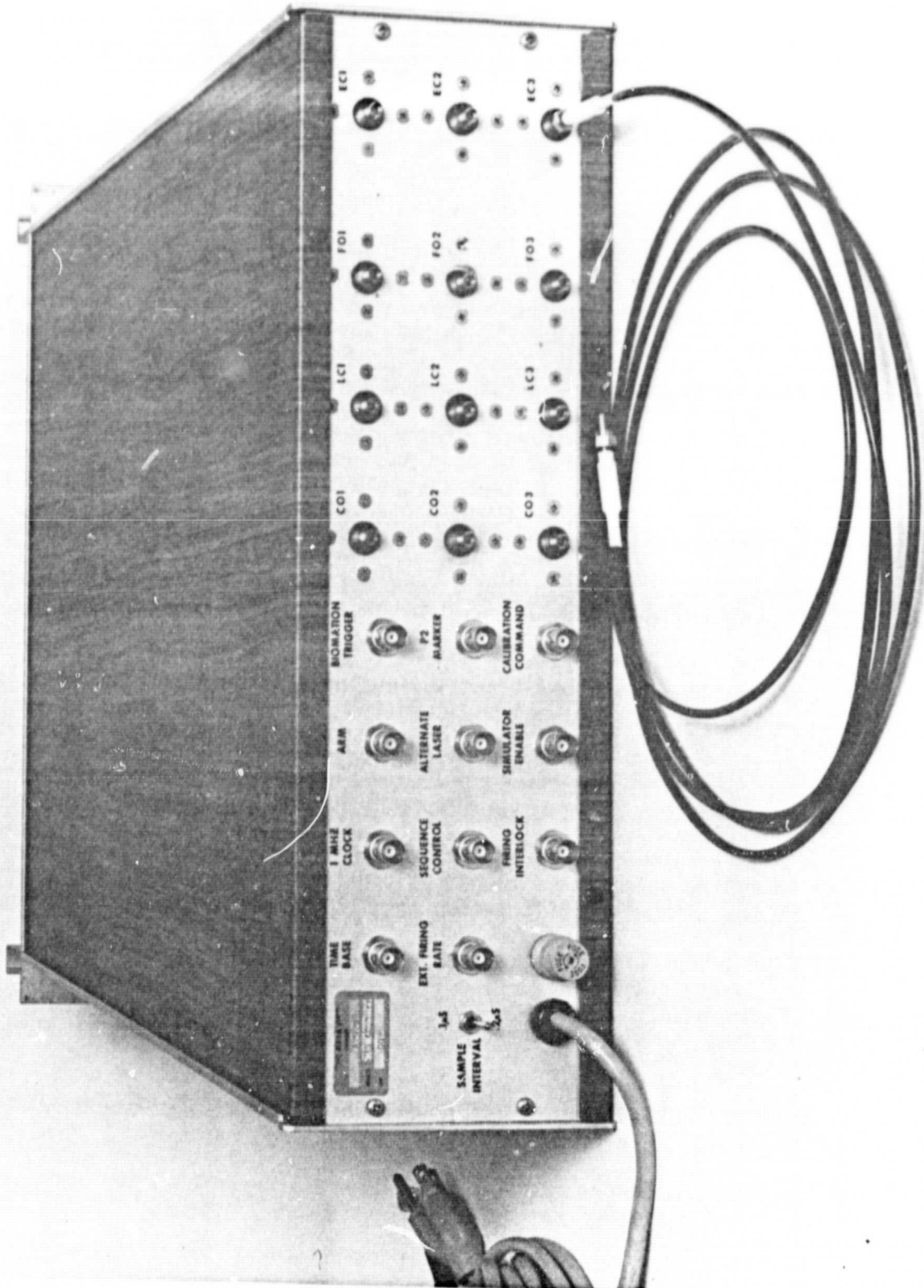


Figure 4B. Photograph of the Master Control Unit rear panel.

Table II. Front Panel Controls, Master Control Unit II (See photograph of Master Control Unit, Fig. 4, and the list of Sequence Timing Pulses, S1-S8, in Table III)

LASER(S) ENABLED--Three toggle switches that allow the selection (in the up position) of pump laser P1, P2 and/or P3.

SEQUENTIAL-2/1 RATE--This toggle switch operates only when all three LASER(S) ENABLED switches are in the up position.

In the SEQUENTIAL position, P1 fires at the sequence time S4; P2 fires at S5; and P3 fires at S6.

In the 2/1 RATE (OFF/ON LINE position), P1 and P2 alternately fire at the sequence time S5, and P3 fires at S6. P3 fires at the rate selected by the FIRING RATE knob; P1 and P2 fire at half the selected rate.

FIRING RATE--This rotary switch selects the firing rate of the lasers. (NOTE: The ON-LINE lasers P1 and P2 fire at half the selected rate in the 2/1 RATE position). The 1, 5 and 10 Hz positions are divided down from the selected Time Base and are very precise. The 10(N)Hz position is 10 Hz NOMINAL or approximately 10 Hz; subsequent Firings are controlled by the END-OF-CHARGE signal from the Quantel lasers. Firing can be controlled by an external source in the EXT position.

SIMULATED RETURN--These toggle switches select the times S4, S5, S6 when the LASER RETURN SIMULATOR will produce a signal (when enabled).

MISFIRE--This normally barely perceivable flashing red light will light for "longer periods of time" indicating a laser misfire. This occurs on the 10 Hz range when the capacitor banks in the Quantel lasers have not reached "full charge" within the 100 ms time period. When this occurs, the 10(N)Hz or a slower Firing Rate should be selected.

LASE--Green light indicating the switches on the Master Control Unit are in the correct position to allow the laser(s) to operate when ON. In particular the FIRING INTERLOCK and the SIMULATOR ENABLE switches must not be selected (in down position). To LASE, these two switches and the STANDBY/OPERATE switch must all be in the up or OPERATE position.

FIRING INTERLOCK--Toggle switch when in the DOWN position will prevent the lasers from firing. The UP position is the LASE or OPERATE position. The main computer can override this switch and prevent the laser(s) from firing by holding a "high" TTL logic output from the assigned port.

OPERATE/STANDBY--Toggle switch when in the DOWN (STANDBY) position will prevent any action with the laser(s) operations.

When in the UP (OPERATE) position will result in the indicated operation depending on the following switch positions:

Table II (continued)

-
- a. ALL THREE SWITCHES IN THE "OPERATE" POSITION: Laser(s) will fire; the simulator will be disabled. The transient digitizer will operate.
 - b. "FIRING INTERLOCK" SELECTED (down); OTHER TWO SWITCHES UP: Laser(s) will not fire and the simulator will be OFF.
 - c. "SIMULATOR ENABLE" SWITCH DOWN; OTHER TWO SWITCHES UP: Laser(s) will not fire and the simulator will produce a return at selected times S4, S5 and/or S6.

SIMULATOR-ENABLE--Toggle switch when selected (in the DOWN position) will prevent the laser(s) from firing and the simulator will produce returns at selected times. When this switch is in the UP position, the lasers can be fired and the simulator is OFF. The main computer can override this switch thereby keeping the laser(s) from firing and activating the simulator.

SYNCHRONIZATION DELAY--Thumb switches that allow the optimum Pockels cell delay to be selected to obtain maximum energy output from the laser(s).

The COARSE delay thumb switch increase the delay of all eight SC (Sequence Control) pulses by 100 μ s (or 50 μ s if selected) for each number increase of the thumb switch.

The two FINE delay thumb switches increase the delay of all eight SC pulses in 1 μ s intervals as indicated by the dial readings. The maximum delay permitted is 49 μ s when operating with 50 μ s SC intervals (time above 50 μ s is marked in RED).

BNC JACKS AS FOLLOWS (Terminate in 50-ohms):

CHARGE DELAY--Displays the maximum delay allowable (99 ms on 10 Hz and 179 ms for slower FIRING RATES) to receive an END-OF-CHARGE signal without a MISFIRE.

END-OF-CHARGE--Indicates the time when all selected laser(s) have obtained fully charged capacitor banks.

FIRING ORDER 1--Positive going pulse (50 or 100 μ s wide) issued to the Quantel laser P1 commanding it to send delayed flashlamp trigger pulses to the oscillator and amplifier flashlamps.

SEQUENCE CONTROL--Eight positive going SCW pulses 10 μ s wide separated either 50 or 100 μ s apart (see Table V for the functions of the S pulses). These SCW pulses are stretched SC pulses widened for easier viewing on the oscilloscope.

LASE COMMAND 1--Positive 50 or 100 μ s wide pulse routed to the Pockels cell in laser P1 as a LASE command.

Table II (Concluded)

LASE COMMAND 2--Positive going pulse routed to the Pockels cell in laser P2.

SCOPE TRIGGER--Positive going pulse selected by the following described rotary switch and used to trigger an oscilloscope.

SCOPE TRIGGER (Trigger Select)--Nine position rotary switch used to select the time of triggering an oscilloscope.

POWER--Toggle switch to control the AC power to the unit.

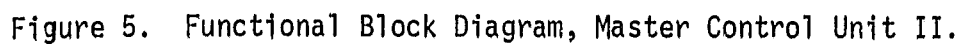
ed by referring to its Functional Block Diagram (Fig. 5) and the timing diagrams (Fig. 6). The selected 5 or 10 MHz time base reference is coupled through an optical isolator/driver (U20, U21) to a Schmitt Trigger inverter/driver used to decrease the rise and fall times of the square wave time base pulse. It is then divided down by U30, 31, and 14 when the time base input is 5 MHz (0.2 μ s sample interval) and by U29 when the time base input is 10 MHz (0.1 μ s sample interval) in order to generate a synchronized 1 MHz clock pulse (CP). This clock is used within the Master Control Unit and routed through U33 and U34 for use elsewhere within the system (Appendix A). U24 and U25 divide the time base nominally by 50 to produce a low frequency clock (CPL) with pulses separated either 50 μ s or 100 μ s used primarily to control the laser firing separation. A DIP switch (U25) allows the selection of other firing rates. The dip switch setting to obtain the above 50 μ s and 100 μ s separations is:

POSITION	-----	1	2	3	4	5	6	7	8
SWITCH SETTING---	U	1	1	0	0	1	1	1	

Figures 6A, B and C show the 50 μ s CPLs for the 0.1 μ s and Figure 6D shows the 100 μ s CPSs for the 0.2 μ s transient digitizer sample interval timing illustrated.

The 1 MHz clock is divided by 10 in U32 to produce a 100 KHz clock used within the Master Control Unit and buffered by U22. The 100 KHz is further divided by U23 and U36 to produce a selectable 1, 5 or 10 Hz (locked) Firing Rate Pulse. The 10 Hz locked Firing Rate separation is 100,000 μ s and is illustrated in Figures 6A and D. A 10(N) Hz nominal firing rate which is not locked to the time base can also be selected. In this position, the firing rate is determined by the "charge time" of the slowest Quantel pump

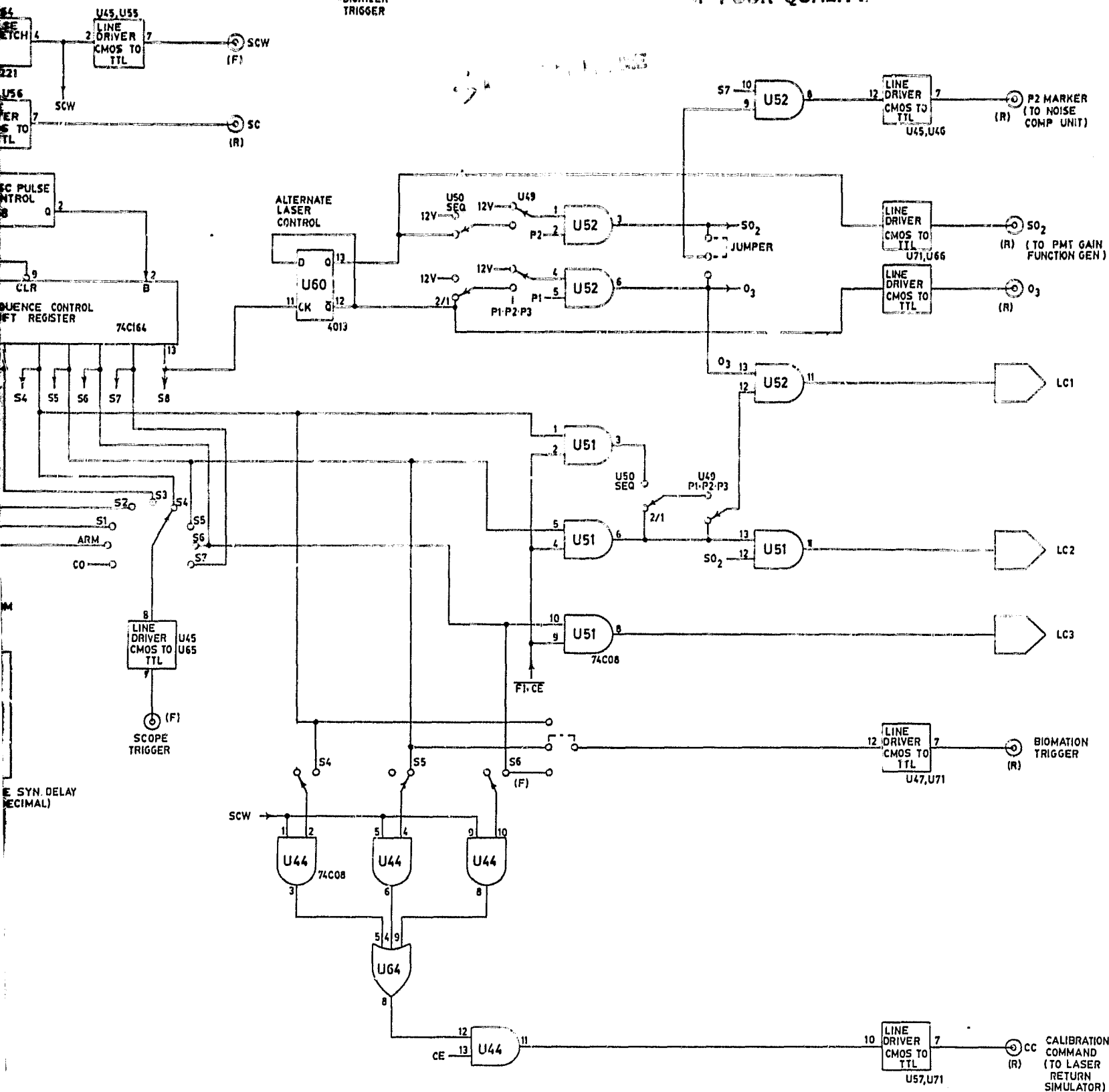
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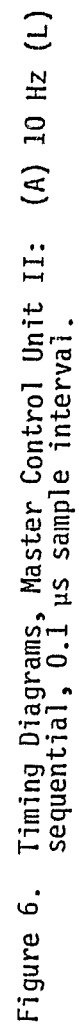


TESTING CODE	SHK* NUMBER	S3	DIGITIZER WORD AND SEQUENCE (S) NUMBERS	S4	S5	S6	S7
1 RATE	n-1		500	1000	1500	2000	
F/ON LINE	n			03 (P1)	OFFLINE (P3)	(NONE)	
SEQUENTIAL	n-1		03 (P1)				P2 MARKER
	n						

DIGITIZER TRIGGER

REPRODUCED FROM
A. FOUR QUALITY.





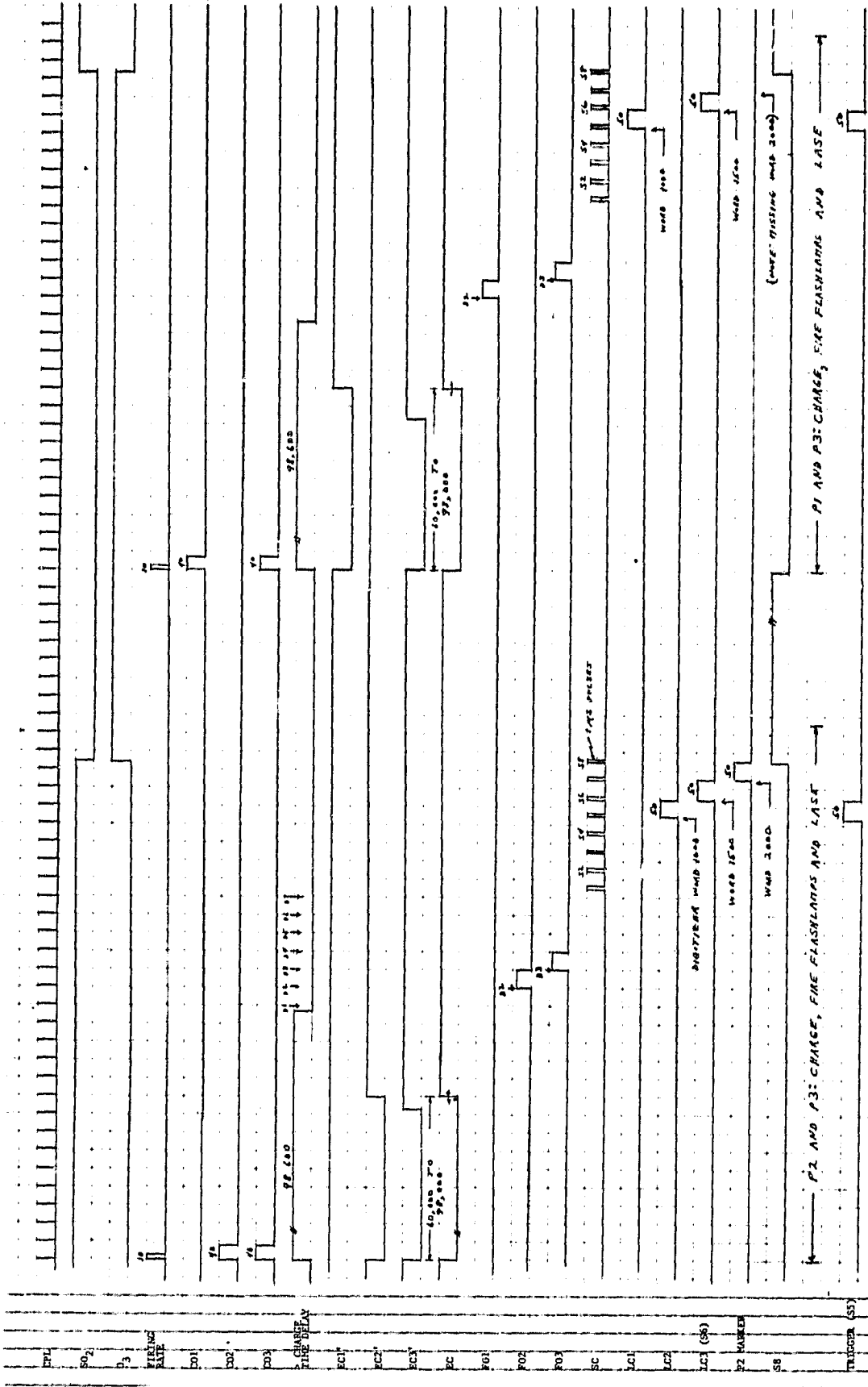


Figure 6. Timing Diagrams, Master Control Unit II: (C) 10 Hz (L) 2/1 rate, 0.1 μs sequential interval.

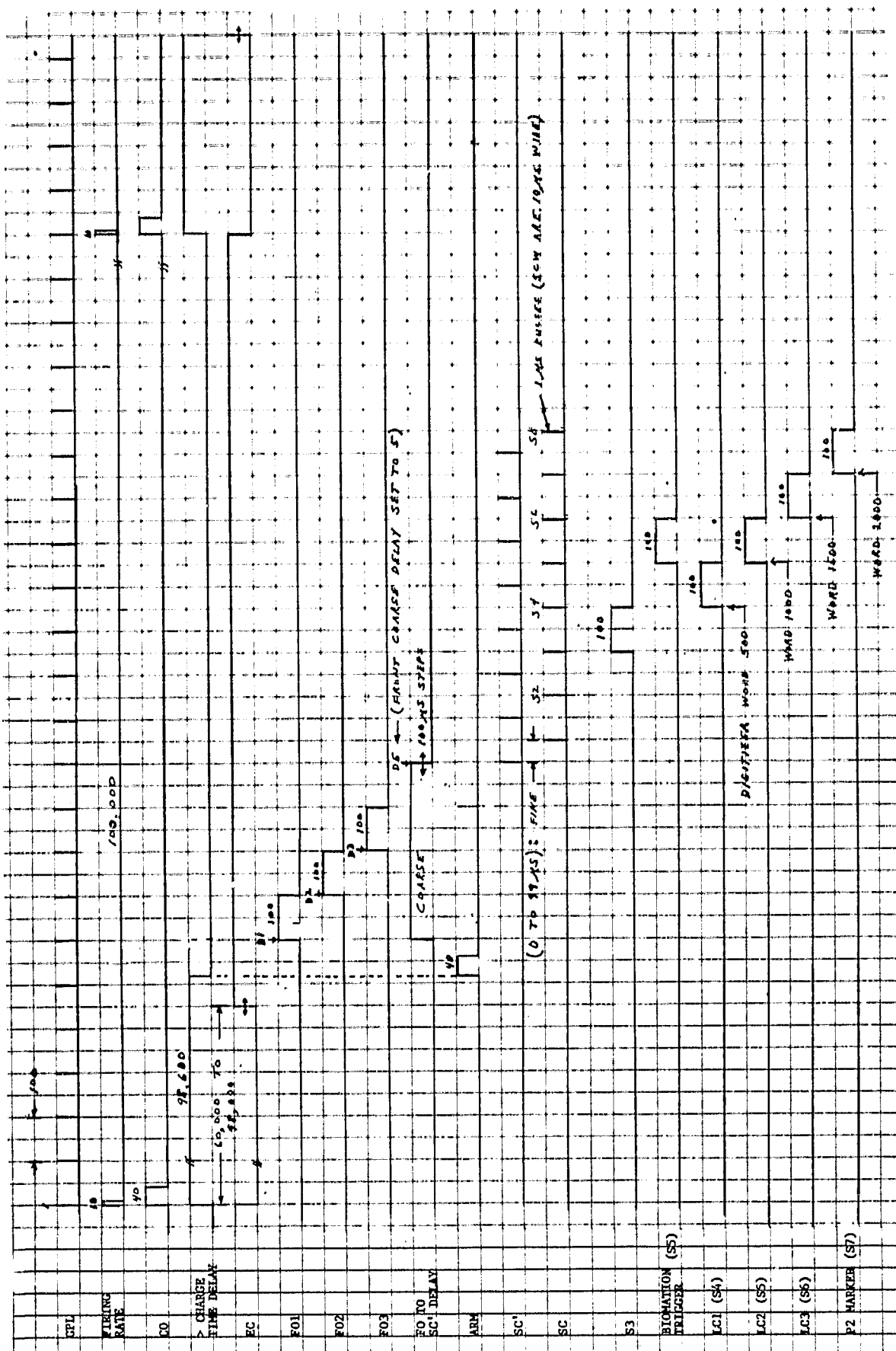


Figure 6. Timing Diagrams, Master Control Unit II: (D) 10 Hz (L) sequential, 0.2 μ s sample interval.

laser added to the maximum "delay time" selected on the front of the Quantel power Units (PU 420/430's). This firing rate will vary with the selected laser power supply voltage due to the capacitor charging time with a high voltage of around 2.1 kv producing a firing rate of about 9.5 Hz and around 1.3 kv producing a firing rate of about 17 Hz. In addition, this 9.5 to 17 Hz firing rate will change from shot to shot due to the variation of the capacitor charging rate. This position should only be used if the laser will not fire in the 10 Hz Time Base Locked position at the output energy level selected. When the Standby-Operate toggle switch is switched to the Operate position, the first pulse to initiate the 10(N) Hz required sequence is produced by the Single Pulse Generator U5, U6 and U26. Subsequent pulses are produced by the S8 time Sequence pulse generated after the third laser has fired as illustrated in the timing diagram Fig. 6B. An external firing rate can also be selected.

These various firing rate pulses trigger a 40 μ s pulse generator (U8) whose output cause the C01, C02 and/or C03 commands to be issued if gates U1, and U9s have been opened by the selected pump lasers P1, P2 and/or P3 front panel toggle switches; and if the O3 and/or S02 signal are present. None of these Charge Orders will be issued if the Firing Interlock (FI) or the Calibration Enable (CE) signal prevent the opening of the C0 gate via U1-1.

The selected Charge Orders are routed to the Quantel Control Unit and cause the capacitor banks within the Quantel pump lasers to "charge." After each capacitor bank has reached full charge, an End-of-Charge signal (EC1, EC2, and/or EC3) is issued by the Quantel control units, routed through optical transmitters and receivers coupled by fiber optics, and inputted to the Master Control Unit via U2, 10 and 11. After all three EC_n pedestals

are present, the AND gate U3 outputs a composite End-of-Charge (EC) signal which can be observed on the front panel. When the Firing Rate switch is in other than the 10 (N) position, the EC pedestal is present on pin 4 of the "charge time delay" gate U31. A 10 μ s Charge Delay (CD) pulse is produced 98,600 μ s after the CO pulse when in the 10 Hz and 179,000 μ s after the CO pulse when in the 1 Hz, 5 Hz or external firing rate position. These delay times are selectable by rewiring U12; the 98,600 μ s delay has been maximized since the 10 Hz locked rate is marginal when maximum energy output is selected by operating the pump laser power supply around 2.1 kv. If the CD pulse arrives ahead of the EC pedestal, a Misfire will occur and the front panel red light marked MISFIRE will flash (controlled via U13). This is due to the EC pedestal remaining for at least an extra 100,000 μ s since it was not terminated within the Quantel by a Fire Order (FO) signal produced within the Master Control Unit and forwarded to the Quantel. If the EC pedestal arrives ahead of the 10 μ s CD pulse to "open" gate U31, the CD pulse will pass through U31 and 15 and produce a 40 μ s synchronized pulse (U14, 17, and 18) routed to three different places: (1) the Scope Trigger selector switch marked ARM, (2) the ARM output rear panel BNC via U33 and 34, and (3) the Set input of the Coarse Delay S-R flip flop U61. This will result in the Coarse Delay Gate U63 being opened to allow n CPL pulses to pass causing the Coarse Delay shift Register, U62, to step n times (with each step producing either a 50 or 100 μ s additional delay depending upon the selected Sample Interval (0.1 or 0.2 μ s). If "6" is selected with the Coarse Synchronization Delay decimal thumb switch as illustrated in Figs. 5 and 6A, the Coarse Delay Shift Register U62 steps six times and produces a pulse D6 that SETS the S-R flip flop U61 resulting in opening the Sequence Control prime (SC') gate U59 the reason for which will be discussed later. The Coarse Delay

Shift Register U62 will continue to step until S3 RESETS the Coarse Delay FF U61. The S3 RESET pulse is produced by the Sequence Control Shift Register U69 and will be discussed later.

Going back for a moment, when the Firing Rate switch is in the 10 (N) Hz position, the leading edge of the EC pedestal passes directly through the exclusive OR gate U15 to accomplish the same Arm and Coarse Delay functions covered above. The CD pulse is ignored and the subsequent sequences (to be described) will occur immediately following the receipt of the leading edge of the EC pedestal.

The Coarse Delay Shift Register stepping produce pulses as illustrated in Fig. 6 identified as D1, 2 and 3 which convert to F01, 2 and 3 and expressed in Boolean prior to simplification as follows (Fig. 5):

$$\begin{aligned} F01 = & D1 \text{ SEQ } (P1 \text{ } P2 \text{ } P3) \text{ } 03 \text{ } (\overline{FI+CE}) + \\ & D2 \text{ } 2/1 \text{ } (P1 \text{ } P2 \text{ } P3) \text{ } 03 \text{ } (\overline{FI+CE}) + \\ & D2 \text{ } (P1 \text{ } P2 \text{ } P3) \text{ } 03 \text{ } (\overline{FI+CE}) \end{aligned} \quad (2)$$

$$F02 = D2 \text{ } S02 \text{ } (\overline{FI+CE}) \quad (3)$$

and

$$F03 = D3 \text{ } (\overline{FI+CE}) \quad (4)$$

Expressed in words, if the fire Interlock or the Calibrate Enable condition have not been selected:

- (1) F01 is issued and fires laser P1 at time --
 - (a) D1 if in the sequential Mode when all three pump lasers P1, 2 and 3 have been selected; or

(d) D2 if in the 2/1 Mode

(2) F02 is issued at D2 and fires laser P2;

(3) F03 is issued at D3 and fires laser P3.

As discussed previously, the selected time base is divided down by U24 to produce a chain of CPL pulses precisely separated either 50 or 100 μ s apart with other separations available if selected by Dip switch U25. After a coarse delay time determined by the front panel decimal thumb switch COARSE SYNCHRONIZATION DELAY, the 8-Pulse Gate Control U61 is SET and the 8-Pulse Gate U59 is open. Sequence Control Prime (SC') pulses pass through the Gate to SET the Fine Delay Control FF U68. This results in the Divide by N 4059 chip U70 to become activated and produce the first SC pulse which will RESET the Fine Delay flip flop U68 deactivating U70 until the next SC' pulse is available. A total of eight of these delayed SC' pulses are produced until S8 RESETS flip flop U61 closing Gate U59. The amount of the Fine Delay time in increments of 1 μ s is selected by the front panel BCD dual thumb switches labeled FINE SYNCRONIZATION DELAY. The maximum fine delay is indicated by the "white" numerals which are limited to 49 μ s when sampling at 0.1 μ s (50 μ s CPLs), and by the "red" numerals which are limited to 99 μ s when sampling at 0.2 μ s (100 μ s CPLs). The Sequence Control Pulse, SC1 through SC8, are outputted as 1 μ s wide pulses to the PMT Gain Function Generator chassis (Appendix A) through U45 and 56; and stretched to 10 μ s wide pulses in U54 (SCW) for use within the Master Control Unit and for scope observation via a BNC located on the front panel.

The SC1 through SC8 pulses cause the Sequence Control Shift Register U69 to step 8 times producing 50 μ s wide (or 100 μ s wide) pulses S1 through S8 for various control functions within the Master Control Unit. S3 for

example RESETS FF U61 and stops further stepping within the Coarse Delay Shift Register. The various functions controlled by Sequence Control pulses SC1 through SC8 external to the Master Control Unit are listed in Table A1, and related internal Sequence pulses (S1 through S8) are listed in Table III.

The Calibration Enable Line (CE) must be HIGH in order for the Calibration Commands (CC) to be issued during Sequence times S4, S5 and S6 as covered above. In addition, all three of the Charge Order, Fire Order and Lase Commands are prevented from being generated when either the Calibration Enable or the Firing Interlock (FI) functions are active ($\overline{FI+CI}$). The CE function is controlled either by placing the front panel Simulator Enable switch in the "up" position, or from the Computer via U40-10 when programmed for Receiver Calibration. The FI function is controlled also either by placing the Firing Interlock switch in the "up" position, or from the Computer via U40-13 when programmed to prevent the laser from firing while still activating the PMT functions.

Detailed logic diagrams are not included in this report but may be obtained through the Electra DIAL project office. The following drawings apply to the Master Control Unit II:

LD-970151 (sheet 1)---Logic: Clocks, Change Order, End-of-Charge and Arm

LD-970151 (sheet 2)---Logic: Firing Order, Sync Delay, Sequence Control, Laser Control

This completes the theory of operation of the Master Control Unit II.

B. Combined Laser Control Interface Unit/Quantel Control Unit

An interface unit was designed and packaged together with a Quantel Pump laser Control Unit CU 401 within one chassis (Fig. 7); it contains

Table III. Sequence, S, Pulses Used Internal to the Master Control Unit
(See Appendix A for Sequence Control, SC, pulses used external)

LABEL	FUNCTION
S1	Operates the First Pulse (SC1) Gate Control U68-2 to prevent subsequent SC pulses from rippling through the serial shift Register U69. Scope trigger when selected by front panel rotary switch. Routed to U5-5 for future use.
S2	Scope trigger when selected.
S3	Controls the closing of Coarse Synchronization Delay Gate U63-8. Scope trigger when selected.
S4	Produce a calibration command (via U44-3, 64-8, 57, and 71 to the Laser Return Simulator) when front panel Simulated Return switch S4 is "up." Produces lase command 1 (LC1) via U51-3 and 52-11 when in the Sequential Model and all three lasers have been selected. Scope trigger when selected.
S5	Produces a calibration command when front panel switch S5 is in the "up" position. Produces LC1 (via U51-6 and 52-11) in the Alternate 2/1 mode resulting in the ozone laser transmitting. Produces LC2 (via U51-6 and 51-11) resulting in the S02 laser transmitting. Scope trigger when selected. Generates Transient Digitizer (Biomation or Transiac) trigger via U47 and 71. A jumper can be moved to select S4 or S6 for this trigger.
S6	Produces a calibration command when front panel switch S6 is in the "up" position. Produces LC3 (via U51-8) resulting in P3 transmitting. Scope trigger when selected.
S7	Generates a marker (via U52-8, 45 and 46) indicating that P2 has transmitted at the S02 wavelength. This can be supplied for recording by the Transient Digitizer beyond the Lidar Return data to indicate that this laser has been fired. Scope trigger when selected.
S8	Causes the 8-pulse SC' gate U59-3 to close (via U40-3 and 61-2) after eight SC' pulses have been passed. Selects via U60-13/12, 52-3 and 52-6 the next laser (S02 or ozone) to be fired. Also can be used externally (via U71-9 and 66-7) in association with the PMT Gain Function Generator and Noise Compensation System (Appendix A) for the alternate recording of the background noise in association with the S02 or ozone received signals.

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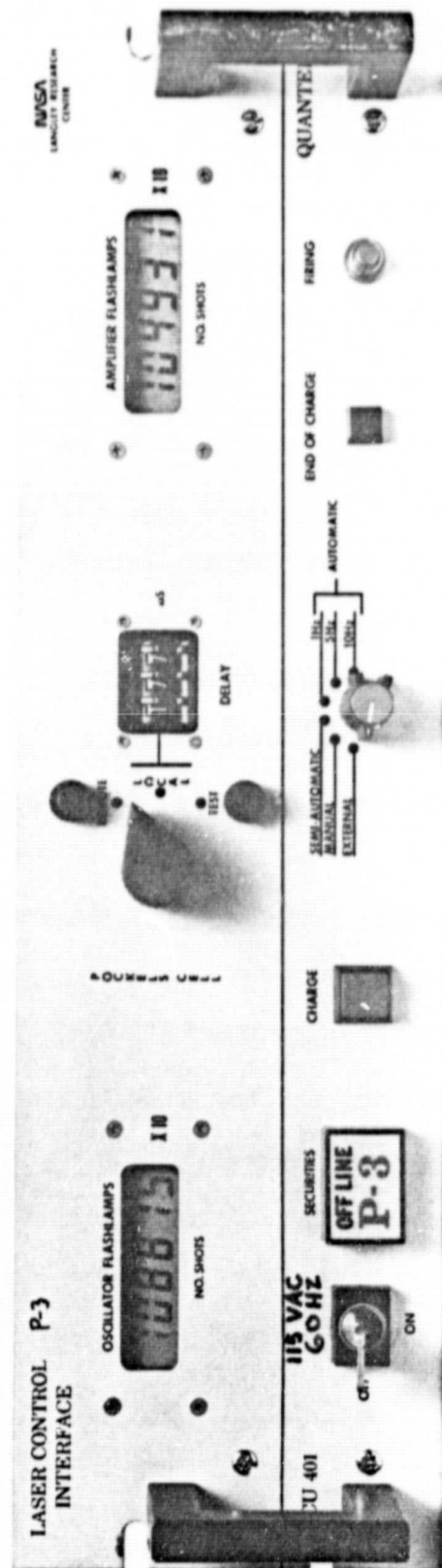


Figure 7. Photograph of the combined NASA Laser Control Interface and the Quantel CU 401 Control Unit.

fiber-optic transmitters and receivers, shot counters, controls and logic. A total of three of these combined units are required to interface the single-chassis Master Control Unit II to the three Quantel Lasers power supplies and heads, and the three Noise Pulse Discriminator/Pockels Cell Pulser Units (discussed next in Section C).

The theory of operation of this combined unit can best be discussed by referring to logic diagram Fig. 8 and the front panel control functions Table IV. Each of the three lasers can be controlled individually when in the INTERNAL/LOCAL mode, or in unison when in the EXTERNAL/REMOTE mode. In the EXTERNAL/REMOTE mode, the Quantel External/Internal rotary switch is positioned in EXTERNAL and the NASA Pockels Cell switch in REMOTE. In the Remote position (Fig. 8), gate U5-8 is closed and gate U5-11 is opened. The Lase Command (LC) pulse passes through U5-11, OR gate U6-5, the LC digital Transmitter and through fiber optics cable to the Noise Pulse Discriminator/Pockels Cell Pulser Unit (to be discussed in Section C). The same process occurs in each of the three Interface Units causing the three pump lasers to Lase as directed by the Master Control Unit (LC1, LC2, and LC3).

When in the INTERNAL/LOCAL mode, the Quantel External/Internal switch is in the INTERNAL position and the NASA Pockels cell switch in the Local position. Gate U5-8 is opened and gate U5-11 is closed. A delayed LC pulse is generated by processing the Quantel PU420 so called "24V" oscillator flashlamp trigger pulse. (It is thus named because this negative going 20 μ s pulse rides on a 24vdc line providing power to the relay and trigger circuits within the Quantel Capacitor Bank Unit, CB 201). This trigger is used within this Interface Unit to enable the counting (via U21, 14, 12 and 11) of 1 MHz clock pulses by U 18, 19 and 20. Front panel thumb switches select the microseconds delay between the Oscillator Flashlamp Trigger and

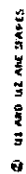


Figure 8. Functional Block Diagram, NASA Laser Control Interface-Unit (part of Combinational Laser Control Unit).

Table IV. Front Panel Controls, Combined NASA Laser Control Interface/
Quantel Control Unit CU 401 (See photograph, Figure 7)

A. QUANTEL CU 401 (Lower section of front panel, Fig. 7)

CONTROL KEY-- This allows the Quantel power supply to be electronically locked and is not removable in the "on" position.

SECURITIES LIGHT (yellow)--Comes ON when the key is switched to the "on" position five seconds before the flashlamp is able to fire if all Security Interlocks are closed.

CHARGE ORDER (push button and red light)--When depressed, will cause the capacitor banks to be "charged" to the selected voltage when operating in MANUAL mode or to "charge" and "automatically fire" when in the SEMI-AUTOMATIC mode. The indicator informs the operator that the capacitor banks within this particular laser are charging.

END-OF-CHARGE LIGHT (Green)--Indicates that the capacitor banks are fully charged.

EXTERNAL/INTERNAL ROTARY SELECTOR SWITCH--Allows the selection of the control of this particular laser either remotely in the EXTERNAL position or locally in the MANUAL, SEMI-AUTOMATIC positions. In the MANUAL position, the laser can be fired first by pressing the Charge Button and then the Fire Button located on this panel; in the SEMI-AUTOMATIC position the capacitor banks are charged automatically and it is only necessary to press the Charge Button; and in the AUTOMATIC position, a firing rate of 1, 5 or 10 Hz is selected and Charging/Firing is automatic and continuous.

FIRING BUTTON--This button fires the flashlamps when in the MANUAL position and the capacitor bank has reached the selected voltage.

B. NASA LASER CONTROL INTERFACE (Upper section of front panel, Fig. 7)

POCKELS CELL (Remote, Local, Test) SWITCH--Controls the triggering of Pockels Cell.

A. REMOTE--Allows the Pockels Cell to be triggered by the Laser Command produced in the Master Control Unit. (The Quantel CU 401 must be in the EXTERNAL mode). The GREEN light indicating this is the "normal" operating mode.

B. LOCAL--Allows the laser to be controlled locally (without the use of the Master Control Unit). Pockels Cell delay is selected by three thumb switches marked DELAY calibrated in microseconds. (The Quantel CU 401 must be in the MANUAL, SEMI-AUTOMATIC, 1, 5 or 10 Hz mode). The RED light indicates this is not the "normal" operating mode.

Table IV. (Concluded)

C. TEST--Prevents the LASE COMMAND from reaching the Pockels Cell during "hold-off" checks of the oscillator cavity. (The position of the Quantel CU 401 mode switch is immaterial). The RED light indicates this is not the "normal" operating mode.

OSCILLATOR FLASHLAMPS NO. SHOTS (Shot Counter)--Records the number of shots accumulated by the oscillator flashlamps (Has a 10-year battery to power the memory retention circuitry when the system is OFF).

AMPLIFIER FLASHLAMPS NO. SHOTS--Records the number of shots accumulated by the amplifier flashlamps.

the production of the Lase Command which increases as the flashlamps age. Counting by U18, 19 and 20 stops (controlled via U13, 12 and 11) when the overflow from U20 causes a 10 μ s pulse to be generated by the One-Shot U13. This 10 μ s pulse also passes through the open Local Gate U5-8, the OK gate U6 and the LC Digital Transmitter to control the Lase of its associated pump laser.

When the Pockels Cell switch is positioned to Test, the local Lase Command is prevented from passing through gate U5-8 thereby keeping the Pockels Cell from being triggered. This allows a "hold-off" check of the oscillator cavity (discussed later in this report).

The 24V oscillator flashlamp trigger is also routed via U7 and 13 to the OSCILLATOR FLASHLAMP SHOT COUNTER. This counter is displayed on the front panel and has a 10-year battery so it retains the total shots until reset by a push button on its side. A second counter displays the total AMPLIFIER FLASHLAMP SHOTS sensed from the Amplifier 24V trigger line.

The Charge Order (CO) and Firing Order (FO) fiber-optic receivers, and the End-of-Charge (EC) fiber-optic transmitter are contained within this chassis; they are wired to the Quantel control circuitry also contained within this combined Quantel/NASA chassis.

C. Noise Pulse Discriminator and Pockels Cell Pulser Unit

This unit (Figs. 9 and 10) accepts an input from the Combined Laser Control Interface/Quantel Control Unit, and causes the Pockels Cell to be opened (Q-switched) at the proper time. It was specially designed to "gate out" the noise spikes occurring from the flashlamp firings that could prematurely activate the Pockels Cell. The unique feature is that the gate control is superimposed on the same fiber optics cable as the Lase Control

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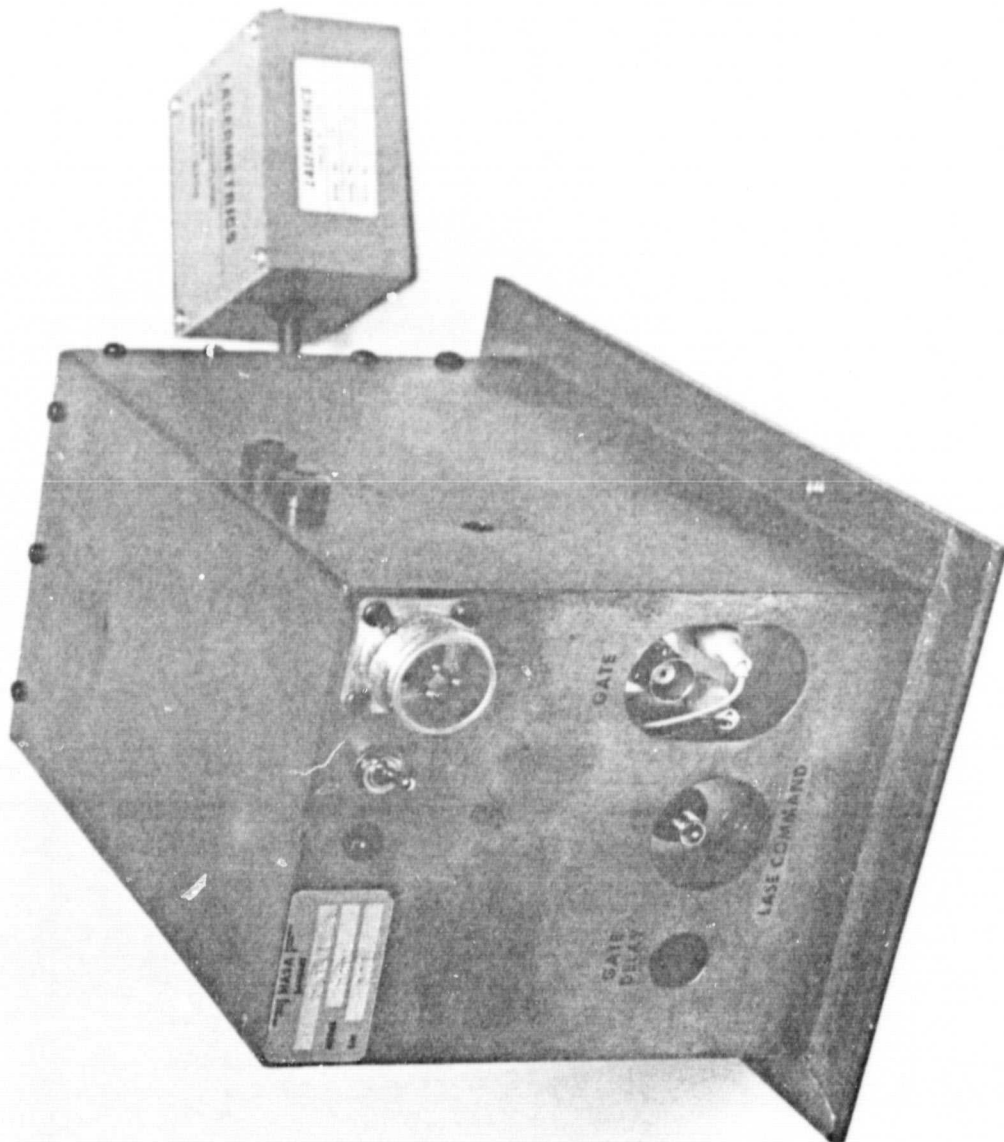
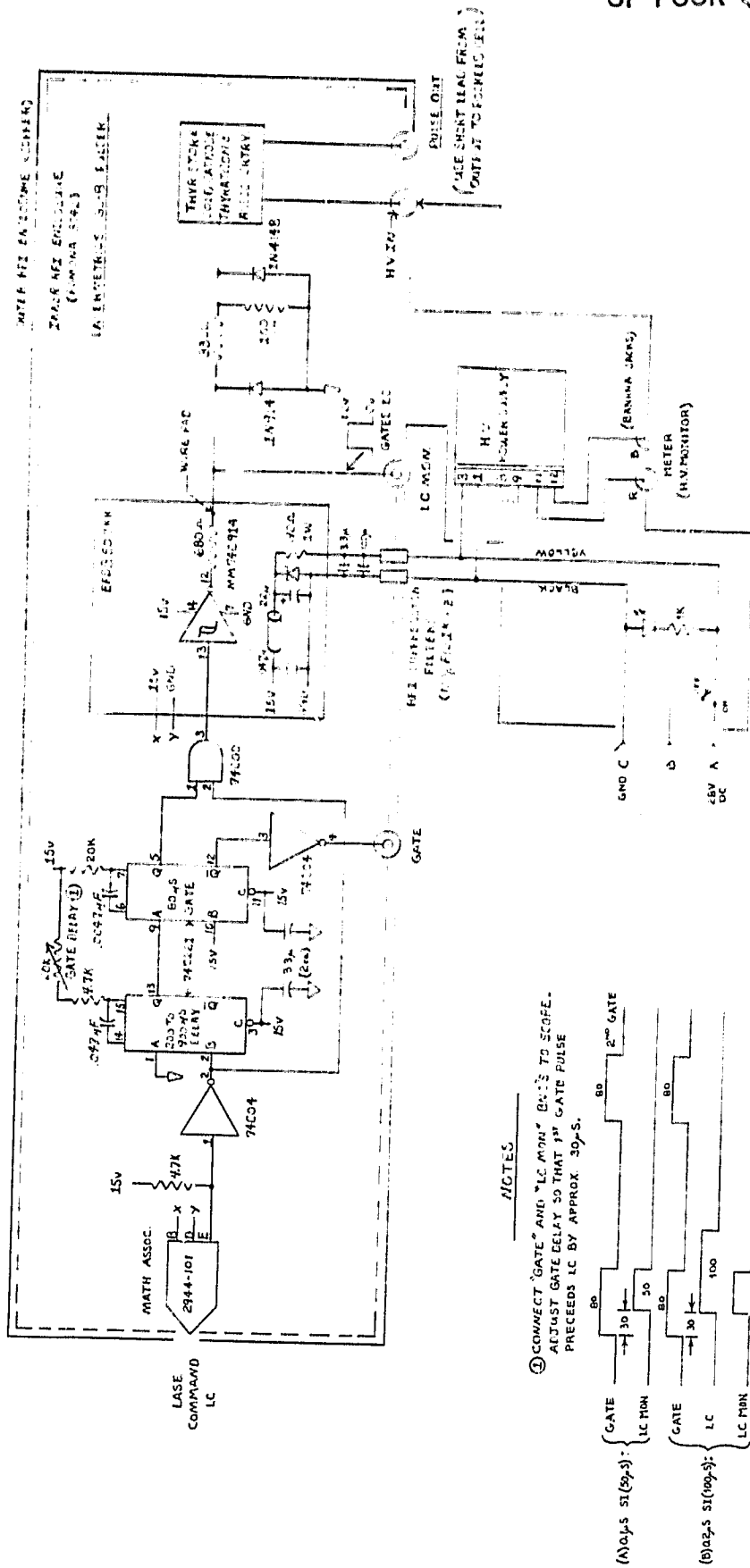


Figure 9. Photograph of the Noise Pulse Discriminator and Pockels Cell Pulser Unit.



pulse. A Firing Signal (FS) preceding the 24V Flashlamp trigger and coming from the Quantel Control Unit via C7-E and U6-3 (Fig. 8) triggers the 200-900 μ s one-shot (Fig. 9). FS is also routed to the 74C00 gate but does not pass since this gate is closed at this time. Noise spikes from the 24V Flashlamp triggers will shortly follow but will also be blocked by the closed 74C00 gate. A second one-shot will then produce an 30 μ s pulse at the delay time determined by the GATE DELAY adjustment. This 30 μ s pulse will open the 74C00 gate approximately 30 μ s (after adjustment) prior to the receipt of the Lase Control (LC) pulse. The LC pulse will therefore pass and trigger the thyristor and cold cathode thyratron causing the Pockels Cell to open resulting in a LASE. This 30 μ s can be decreased if noise is a problem especially when three lasers are firing in a sequential mode. Correct alignment procedures of this and other units associated with the Three Laser Fiberoptic Precision Control System are discussed in the next section of this report.

CALIBRATION PROCEDURES

This section describes the procedure for adjusting various delays to produce the maximum energy at the proper time from each of the three Nd-YAG lasers pumping the three dye lasers. The 10 Hz (L) Time Base Locked sequential mode of operation with 100 μ s separation is selected to illustrate this procedure. This means that pump laser P1 will be lasing at time S4, 100 μ s later P2 will be lasing at time S5 and 100 μ s later P3 will be lasing at time S6. This sequence will be repeated 100 milliseconds later in this 10 Hz (L) mode, or as fast as the capacitors can charge in the 10 Hz (N) mode. The same calibration procedure applies for either 100 or 50 μ s separation, and for the alternative mode. Recalibration will be required if 50 μ s separations are selected after operating with 100 μ s separations since delay time will be different.

A composite functional block diagram (Fig. 11) indicates the delays and BNC outputs used during calibrations. The selected 10 or 5 MHz Time Base is divided to produce 1 MHz and low frequency clocks, and the Firing Rate frequencies. Simultaneous CHARGE ORDERS (CO) are issued for the Quantel Pump laser to charge their capacitor banks as illustrated in the timing diagram (Fig. 12). The charge period may vary between each of the three lasers depending upon the Flashlamp High Voltage selected on the front panel of the Quantel PU 420 and PU 430. After the capacitors are fully charged, End-of-Charge (EC) signals will be issued by the Oscillator and Amplifiers charging circuitry. The third laser to reach full charge produces an EC pedestal within the Master Control Unit which opens a gate and passes a "greater than charge time delay" pulse CD which produces an Arm signal and the first Firing Order (F01). Since CD is locked to the 10 Hz firing rate, it occurs precisely at 100,000 μ s intervals delayed a preselected 98,600 μ s

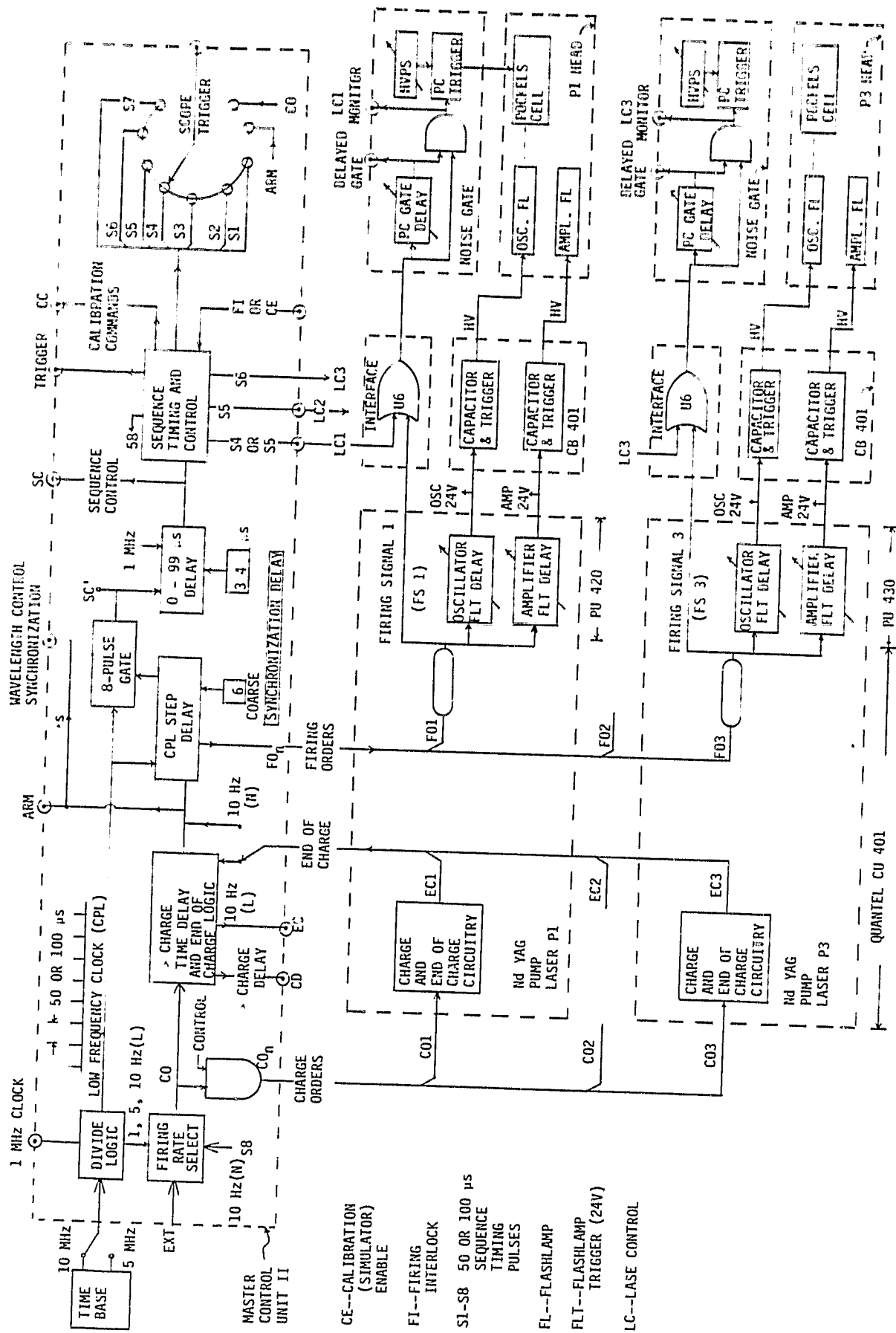


Figure 11. Composite Functional Block Diagram for System Calibration.

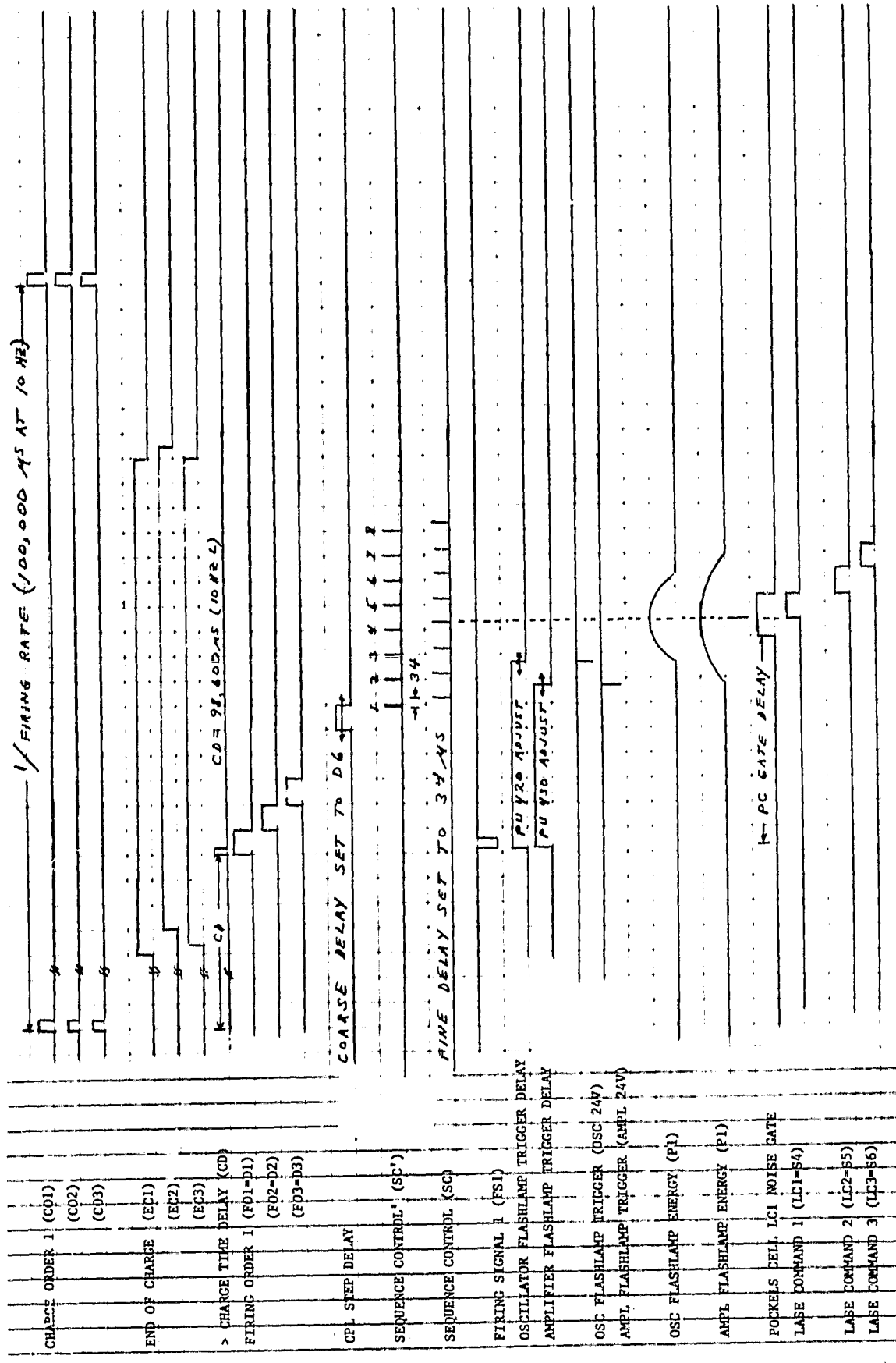


Figure 12. System Timing Diagram.

from the time the Charge Orders were issued. When in the 10 Hz(N) nominal mode, the Arm and F01 signals are produced immediately by the third End-of-Charge signal and the time intervals between subsequent F01 commands can vary up or down from the 100,000 μ s nominal.

F01 is routed to the Quantel Pump Laser P1 through a small delay to produce the Firing Signal 1 (FS1) negative going pulse (Fig. 12). The Oscillator and Amplifier flashlamp trigger delays and the Pockels Cell gate delay are referenced to FS1. The flashlamp trigger delays are adjusted to compensate for the different impedances and aging of the flashlamps, and are adjusted to produce the peak of the energy curves at the precise time that the Lase Command (LC1) is issued. The Pockels Cell Noise Gate delay (also referenced to FS1) is adjusted to open just ahead of the arrival of LC1. Noise spikes generated by the Oscillator and Amplifier flashlamp triggers are prevented from triggering the Pockels Cell since this gate is closed at the time of these triggers. P2 and P3 have duplicate timing to that described above except all pulses and energy curves are delayed by 100 μ s.

F01 is issued at delay time D1, F02 at D2 and F03 at D3 when subsequent CPLs occur (100 μ s for our illustration). The CPL Step Delay serial shift register produces a total of 8 step delays (D1-D8). A front panel thumb switch selects the COARSE delay time (D6 for our illustration) used to control the start of the eight Sequence Control Prime (SC') pulses. These SC' pulses are further delayed from 0 to 99 μ s as selected by two FINE delay thumb switches to produce the eight SC pulses (which also correspond time wise to the S pulses). When the three-laser sequential mode is selected, S4 produces LC1, S5 LC2 and S6 LC3. Any of the S pulses, the Arm and Charge Order pulses may be selected to trigger an oscilloscope.

The Calibration Procedure is initiated by first optimizing each of the three lasers individually in the Local mode as follows:

- (1) Set the oscillator PU 420 delay (Fig. 13) to about mid-range, and connect the Scope Trigger to the BNC marked 24 V.
- (2) Connect the BNCs marked GATE and LC MON to the scope inputs. There is more than one PC noise gate; perform all adjustments using the first 80 μ s wide gate.
- (3) Select the LOCAL and desired FIRING RATE positions on the front panel of the Laser Control Interface/CU 401 unit, and adjust the Thumb Switches marked PCKELS CELL DELAY so that the leading edge of the LASE CONTROL (LC) pulse (observed on the LC MON BNC) is approximately centered under the gate.
- (4) Observe the 1064 nm energy and adjust the PC Thumb Switch until maximum energy is obtained. As the leading edge of the LC pulse approaches the edge of the PC Noise Gate, adjust the "screw drive" pot marked GATE DELAY (accessible from the outside of the copper box surrounding the Noise Pulse Discriminator and Pockels Cell Pulser Unit) to recenter LC. Two or three iterations may be required to obtain maximum energy. (Check this by increasing and decreasing the Thumb Switch Delay and observing that the energy decreases on both sides of the selected Delay setting. Make sure that the LC pulse stays under the Noise Gate).
- (5) Adjust the delay on the PU 420s or 430 used to supply power to the amplifiers for maximum 1064 nm energy. If insufficient range is available on these delay adjustments, reset the oscillator delay and repeat steps 3 and 4. Note the PC Thumb Switch delay time in the LOCAL mode because it will not be changed. Also note the

FIRING ORDER (FO)

FIRING SIGNAL (FS)

OSCILLATOR FLASHLAMP
TRIGGER (24V)

OSCILLATOR FLASHLAMP
ENERGY

NOISE GATE

LASE CONTROL (LC)

AMPLIFIERS(S) FLASH-
LAMP TRIGGER (24V)

AMPLIFIER(S) FLASH-
LAMP ENERGY

small fixed delay

PU 420 osc. delay adj.

PC gate delay adj.

PC delay adj.

PU 430 ampl.
delay adj.

ORIGINAL
OF POOR QUALITY

lase

noise

center leading edge
under noise gate

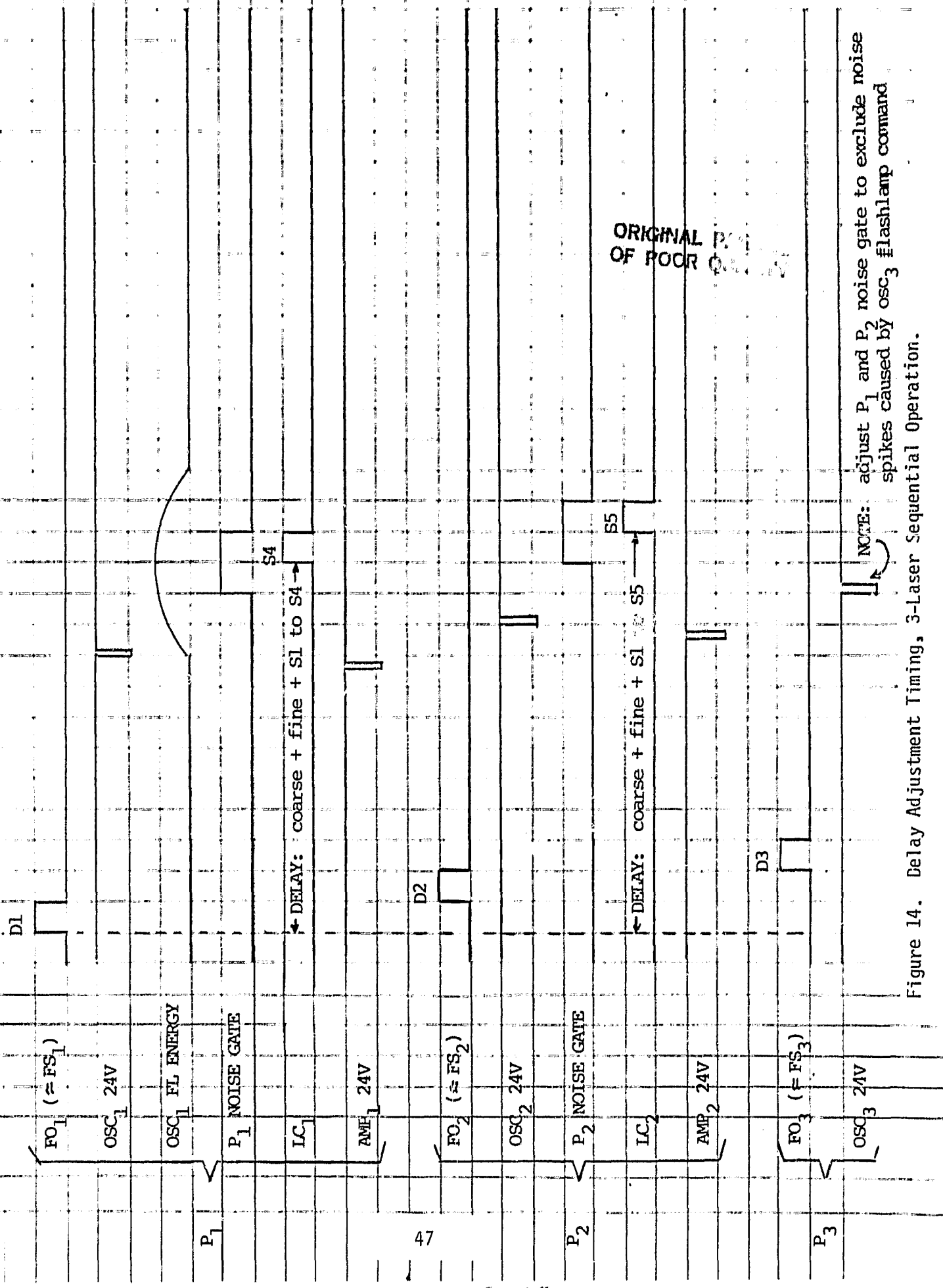
Figure 13. Delay Adjustment Timing, Laser Local Operation.

energy output reading since this same energy should be obtained in the REMOTE mode. Repeat the above procedure for the other two lasers.

The next steps are to calibrate the three lasers for synchronous operation as follows (Fig. 14):

- (5) Switch to REMOTE and EXTERNAL positions on the Laser Control Interface/CO 401 unit; select P1 (or P2), and the desired FIRING RATE on the Master Control Unit.
- (7) Adjust the COARSE and FINE SYNCHRONIZATION DELAYS until maximum energy is observed at 1064 nm. The position of the leading edge of the LC pulse within the PC Noise Gate will not be affected by these Master Control Delay adjustments. The energy reading should be the same as obtained previously for this laser. Note the SYNCHRONIZATION DELAY settings at this time since these will not be changed.
- (8) Select P3 in addition to the laser already selected.
- (9) Move the meter and observe the 1064 nm energy from P3. If it is less than that obtained previously, readjust the OSCILLATOR DELAY on the front of PU 420 for maximum energy while maintaining LC3 within the NOISE GATE. Then readjust the AMPLIFIER(S) DELAY on the front panel of PU 430 for maximum energy. Readjust the Oscillator if necessary. The final reading should be approximately the same as obtained previously.
- (10) Select ALL 3 lasers and the SEQUENTIAL mode.
- (11) Repeat step 9 above.

Pockels Cell "hold off" capability is determined by selecting the TEST position with the Pockels Cell rotary switch located on the Combined Laser



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Figure 14. Delay Adjustment Timing, 3-Laser Sequential Operation.

Control Unit. This removes the Pockels Cell "lase command" and therefore its polarization remains unchanged while the flashlamps are still fired. No (or little) lasing should occur if the optics are in proper alignment.

Operation in the long pulse mode is accomplished by turning off the high voltage supplied to the Pockels Cell. (The position of the Pockels Cell switch is immaterial). The energy measured in this mode is always equal to or greater than that obtained in the Q-switched mode. Selection of this long pulse mode of lasing reduces the energy density on the optics and allows optics alignment with reduced chance of damage.

This completes the Calibration Procedures. Appendix A contains additional information concerning the complete NASA Multipurpose Airborne Differential Absorption System.

ACKNOWLEDGEMENTS

This effort was supported by funds provided under Cooperative Agreement NCC1-32, Dr. E. V. Browell, technical monitor. Coordination of this project was provided by Arlen Carter, DIAL System Manager. Woodrow W. Midgette, Jr., Electronics Packaging Designer from the NASA Electronics Technology Branch, handled the chassis fabrication. William J. McCabe offered certain logic design suggestions, handled the debugging processes and provided general technician support. Carolyn F. Butler was responsible for system programming and was helpful in providing computer support during hardware development tests. Skilled technical support in the development and operation of this multipurpose DIAL system was also provided by Neale Mayo, Norm McKae, Loyd Overbay, Dr. Scott Shipley and Jim Siviter.

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APPENDIX A
BRIEF DESCRIPTION AND PHOTOGRAPHS OF UNITS DEVELOPED
UNDER THIS CONTRACT FOR USE WITH THE NASA
THREE-LASER MULTIPURPOSE AIRBORNE DIFFERENTIAL
ABSORPTION LIDAR SYSTEM

INTRODUCTION

This appendix describes the majority of units (chassis) developed under this contract and used in the NASA three-laser multipurpose airborne DIAL system. The remainder of the units are covered in the main body of this report. In addition, a brief discussion of the French wavelength control unit is included as a lead-in to the NASA wavelength control interface unit. The pump and dye lasers, and the transient digitizers (waveform recorders) are not covered since they were purchased units with separate existing documentation. A photograph of the two-laser enclosure and receiving telescope, and a general block diagram of the NASA airborne DIAL system are featured on the cover of the February 1983 Applied Optics. Transmitter and receiver characteristics are included in the accompanying paper by Browell et al. (ref. 1). The computer system and associated software are described in previously published reports by Butler et al. (ref. 2, 3). Some of the results obtained with this system during observation from the NASA electra aircraft (Fig. A1), and future high altitude (21 km) and space programs are described in references 1, and 4 thru 6.

A simplified system block diagram is included as Fig. 1 in the body of this report. Where feasible, 50 ohm terminators have been installed inside the chassis and are so indicated near the connectors on the rear of each chassis. When a signal is routed to more than one chassis, the 50 ohm terminator is installed at the terminating end of the cabling. Additional information concerning intercabling, termination and mnemonic definitions are contained within reference 2. Sequence Control (SC) pulses used in various places within the system are listed in Table A1.

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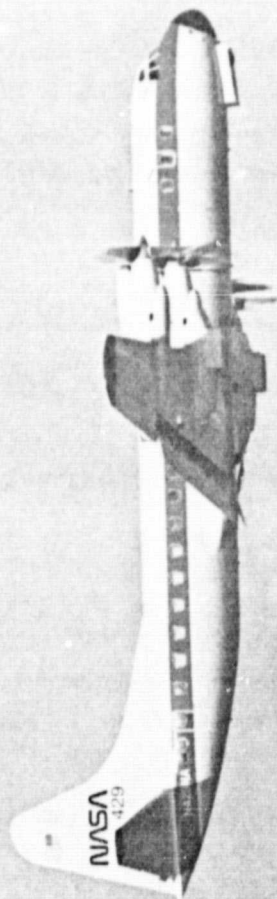


Figure A1. Lockheed Electra Aircraft Used by NASA for DIAL Observations.

Photographs of the DIAL system installed within this aircraft are shown on the cover of Applied Optics and within the article by Browell et al. (Ref. 1).

Table A1. Sequence control (SC) Pulses

LABEL	FUNCTION
SC1	Reserved to use with the Noise Compensation System (described in this Appendix) to control the storing of received ON-LINE noise at the preselected PMT step gains prior to LASE.
SC2	Reserved to control the storing of received OFF-LINE noise.
SC3	Reserved to control the Subtraction of stored from received ON-LINE noise prior to LASE. This difference is recorded.
SC4	(A) ALTERNATE LASER CONTROL MODE--Reserved to control the Subtraction of OFF-LINE noise. The difference is recorded. (B) SEQUENTIAL LASER CONTROL MODE--Used to produce S4 for control of the Quantel pump laser P1 LASING.
SC5	(A) ALTERNATE LASER CONTROL MODE--Used to produce S5 for control of: (1) The alternate LASING of P1 and P2, and (2) The TRIGGERING of the transient digitizers. (B) SEQUENTIAL LASER CONTROL MODE--Used to produce S5 for control of: (1) The LASING of P2, and (2) The TRIGGERING of the transient digitizers.
SC6	Used to produce S6 for control of P3 LASING.
SC7	Used to provide a Marker to the transient digitizer for recording when in the ALTERNATE LASER CONTROL MODE to indicate that laser P2 is now firing.
SC8	Produces S8 which is only used internal to the Master Control Unit.
SC1-SC8	Provided to the PMT Gain Function Generator for initiating the start of the gain steps or other gain funtions.

BRIEF DESCRIPTION OF INDIVIDUAL CHASSIS

Lase-Coherent Time Base (Drawing 970195)

This unit (Fig. A2) receives Arm, on-line lase A time zero (t_0A) and off-line lase B time zero (t_0B) inputs and provides: (1) 5 and 10 M Hz square wave outputs that are stopped and restarted properly phased each time a laser transmits, (2) precision time markers that are inserted along with the return signal into the input of the digitizers, and (3) a digitizer trigger. The time zero inputs are light signal routed from the polished end of a light-pipe (looking at scattered light from the laser transmitting optics) to fast photodiodes installed within the Time Base unit.

The heart of the Time Base is a zero phase error clock pulse generator manufactured by Berkeley Nucleonics Corp. It contains a 100 MHz crystal oscillator with long-term stability which is coupled to a voltage controlled oscillator (VCO) which can be stopped and restarted as well as phase-locked to the crystal oscillator. After the Lase signal is received, the VCO is stopped for about 30 ns then restarted so that its 100 M Hz output is now synchronized with respect to the time of Lase. Phase differences between the crystal oscillator and the VCO for this particular Lase are compared and corrected every 1 μ s and maintained until the next Lase signal is received.

The 100 MHz VCO output is divided down in frequency and supplied through line drivers to BNCs as 5 and 10 M Hz square waves Time Base outputs. The total "stop time" of these time bases due to reset and gating within the divide-down logic and the clock pulse generator is less than 125 ns which does not affect the digitizers or the other units using these outputs. The amount of jitter between the time zero input and the leading edge of the restarted time base is less than 4 ns for 300 shots as recorded with

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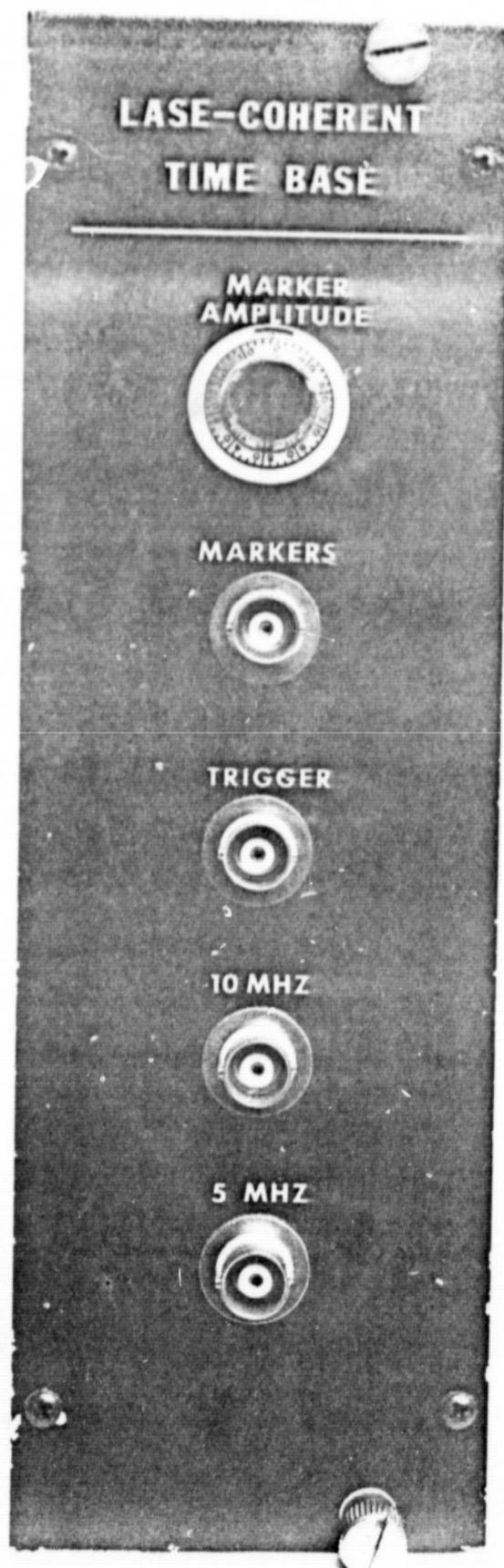


Figure A2. Photograph of the Lase-Coherent Time Base.

a scope camera.

First pulse logic selects a $0.2\ \mu\text{s}$ wide precision delayed time markers each time one of the lasers transmits. These are outputted through line drivers as negative or positive 1-word wide (using a $0.2\ \mu\text{s}$ sample interval) markers whose amplitude can be adjusted to just saturate the selected digitizer voltage range. Two of these markers will be inserted into the return data: one as an on-line and the other as an off-line marker.

Single pulse logic selects a single digitizer trigger for each pulse pair transmitted at the time the first (on-line) laser transmits.

PMT GAIN CONTROL SYSTEM

The purpose of the PMT Gain Control System, as its name implies, is to control the gain of the photomultiplier tubes. It consists of three PMT Gain Function Generators chassis, a single three-channel PMT Dynode and Focus Driver chassis, and a separate 150 vdc power supply.

PMT Gain is controlled in this DIAL system in two different manners by biasing one or more of the PMT elements for reduced gain and then after lase: (1) supplying a 320 v or less flat top pedestal to the focusing electrode or dynode(s) to restore full gain for the duration of the return signal (under $100\ \mu\text{s}$), and (2) supplying a 45 v or less function (such as $1/R^2$) to the even numbered dynodes in a manner first described by Allen and Evans (ref. 7). Each of the chassis will be discussed separately.

A. PMT Gain Function Generator (Drawings 1477-4 and 1477-11)

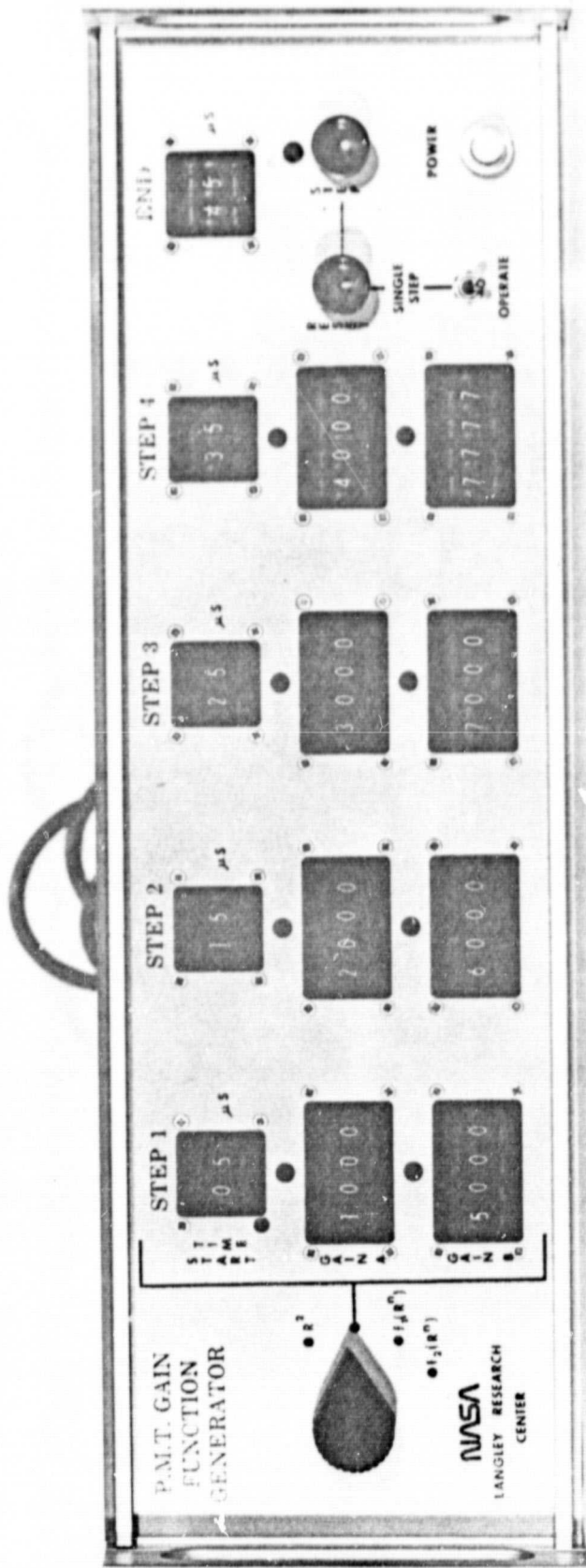
This chassis receives eight Sequence Control (SC1-SC8) pulses from the Master Control and generates either a single or multiple (up to 4) step voltages following each SC pulse. These steps are front panel selectable

(Fig. A3) within a 0 to 14 volt range which will control the PMT gain by 42 dB using the even dynode "low voltage" control method. Four different gain steps can be selected by the top row thumb wheel switches to control the on-line PMT gain following each odd numbered SC pulse and four new gain steps can be selected by the bottom row switches to control the off-line gain following each even numbered SC pulse. This will allow a greater dynamic range of operation by increasing the PMT gain as the return is decreasing with the square of the range. The time after lase for each of the four gain steps to start is also front panel selectable, and are equal for both the on- and off-line gain steps. The end of the fourth step can also be selected. A single step may be produced by setting the Start Time thumb switches for Steps 2, 3, and 4 to times greater than the end time. Provisions have been incorporated for the future addition of logic to produce range squared (R^2) or some function of R^n for PMT even dynode gain control purposes.

This chassis also outputs focus gates triggers for controlling on-line gain by the "high voltage" method following each odd numbered SC pulse, and off-line gain following each even numbered SC pulse. These are routed to the PMT Dynode and Focus Driver chassis which will be discussed next.

B. PMT Dynode and Focus Driver (Drawing 1477-1 and 1477-9)

This chassis (Fig. A4) has three duplicate channels. It receives the focus gate triggers from the PMT Gain Function Generator and produces a 320 v or less pedestal for controlling PMT gain by the "high voltage" method. Pedestals between 100 and 320 volts can be selected by front panel Focus Gate Level pots for controlling the on-line "A" gain, and the off-line "B" gain. The on-line gain is usually set to maximum since the return



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Figure A3. Photograph of the PMT Gain Function Generator.

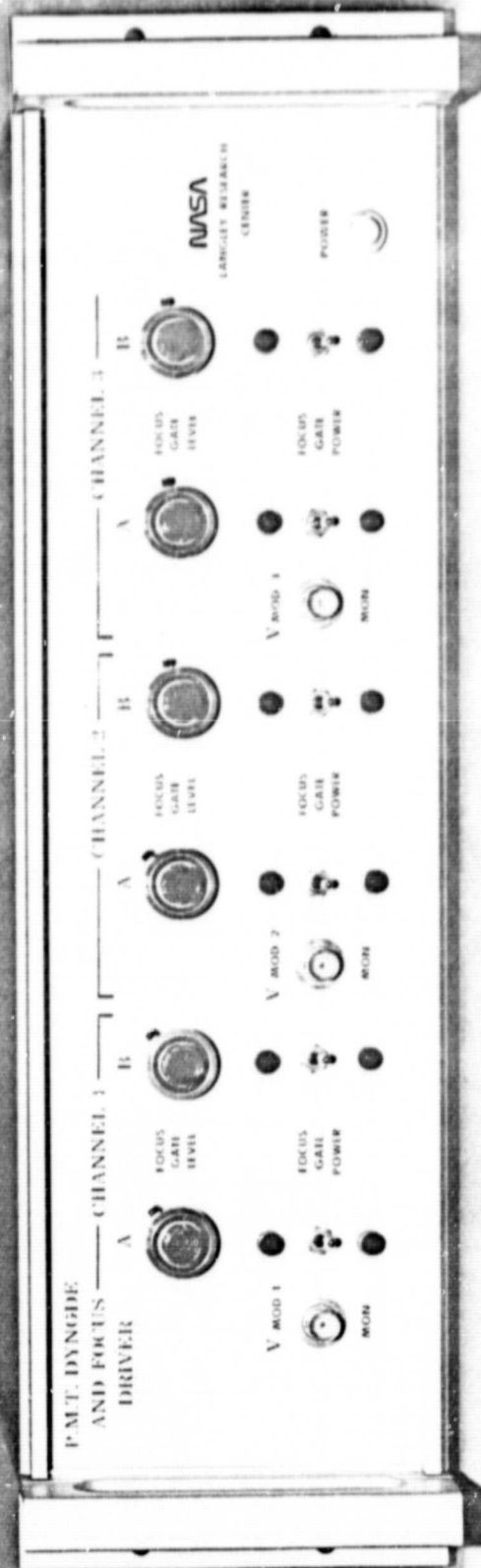


Figure A4. Photograph of the PMT DYNODE and Focus Driver.

signal is absorbed by the gas species being measured, and the off-line to some lower value so that the two return signals are approximately equal in amplitude. These high-voltage control signals are coupled to the PMT bleeder network through a 3000 v coupling capacitor.

The 0 to 14 v step pulses are inputted to this chassis where they are amplified to a 0 to -45 v step used to control the PMT gain by the "low voltage" method. BNCs are installed on the front panel to monitor the shape of this V_{mod} (voltage modulating) pulse.

Wavelength Control System

The Wavelength Control System is used in this airborne DIAL system to maintain high-precision control of the on-line dye laser wavelength. This is particularly important during water vapor measurements since the spectral width of the water vapor line around 724 nm is very narrow. The main portion of the system was developed under the direction of M. L. Chanin at the Centre Nationale Recherche Spatiale (National Center for Space Research), Verrieres le Buisson, France. The DIAL interface unit was developed under this contract and fabricated by NASA and is used to synchronize the wavelength control functions with the firing of the lasers. Each of these chassis will be discussed separately.

A. French Wavelength Control Unit

Informal block diagrams, drawing and notes (some of which are in French) were supplied with the equipment. A photograph of the main electronics chassis is shown in Fig. A5, and a block diagram and brief explanation of the unit operation is contained on page 527 of reference 1.

The wavelength control unit is a closed servo system referenced to a

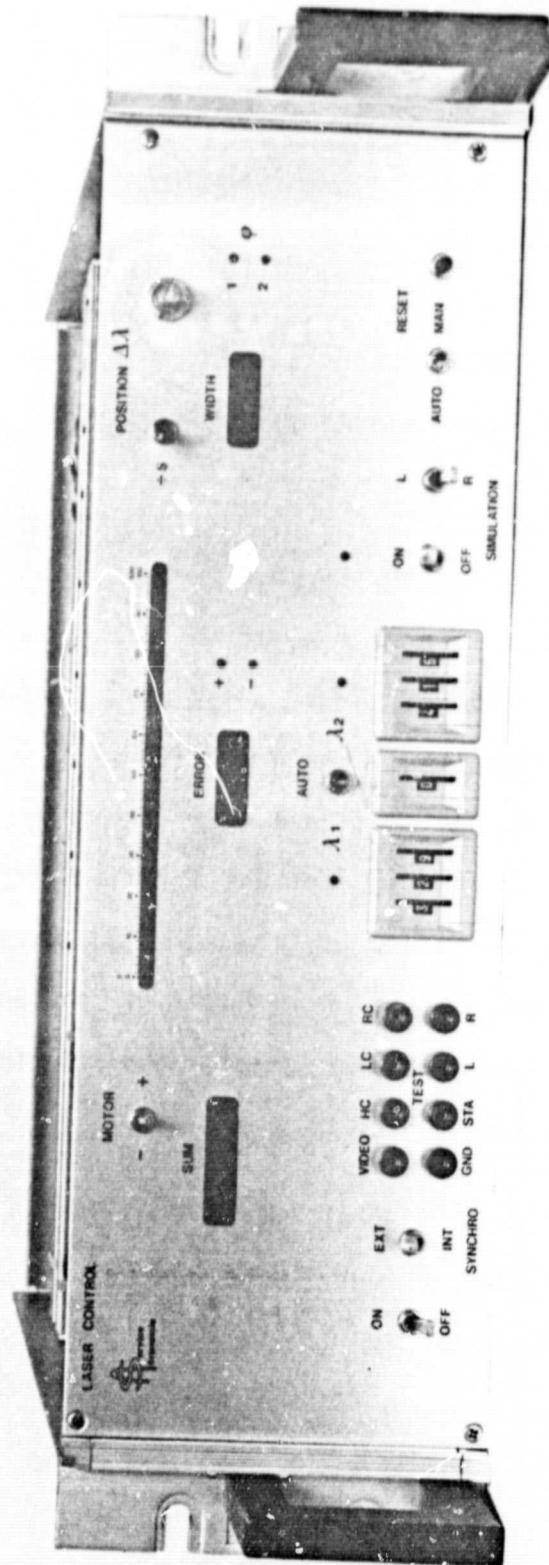


Figure A5. Photograph of the CNRS (French) Wavelength Control Unit.

Hewlett-Packard stabilized He-Ne laser operating at 632.914 nm. The reference and the dye laser beams are alternately passed through a Fizeau interferometer which consists of an input up-collimator, a wedge, and output cylindrical lens. The output lens focuses the interference fringes onto a 512 element solid state linear photodiode array/scanner (EG and G Reticon). Video signals from this array are stored in memory and the position of the reference and dye laser fringe centroids are computed. The number of elements between these fringes is compared to thumbwheel inputs on the control panel (Fig. A5) and the difference between these readings is used to reposition a holographic grating for fine tuning the wavelength. Wavelength can be maintained to within 0.3 pm of its initialized wavelength. The Reticon is scanned every 7 milliseconds except for periods immediately preceeding, during the immediately following lasing of the pump and dye lasers. Synchronization is provided by the interface unit to be described next.

B. NASA Wavelength Control Interface Unit (Drawing 1477-26)

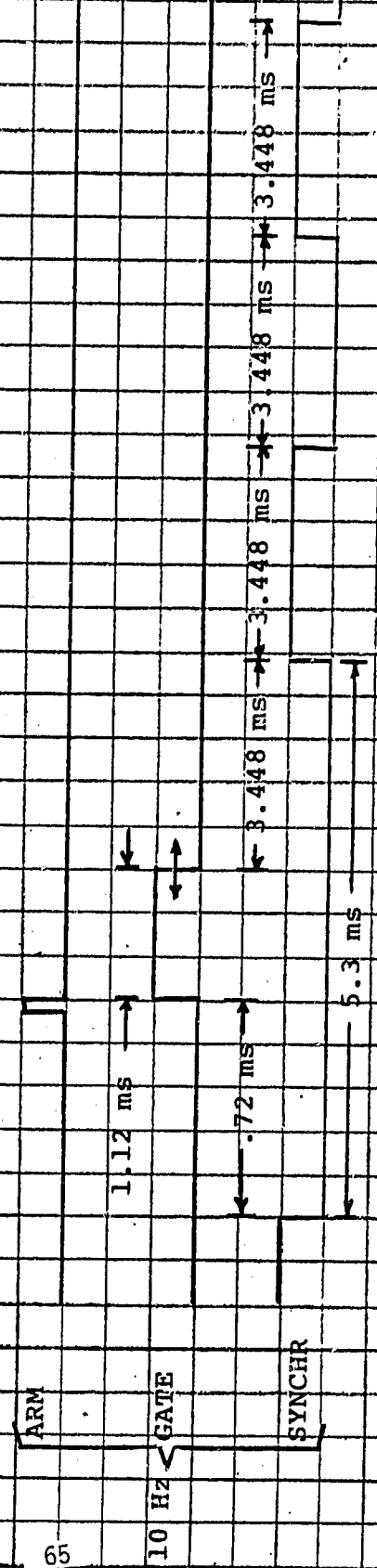
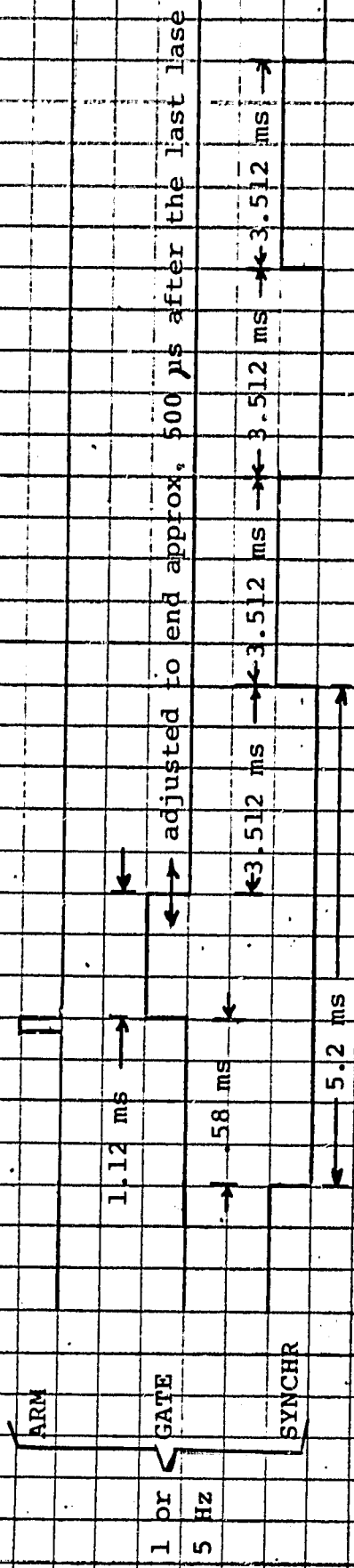
This unit (Fig. A6) synchronizes the operation of the French Wavelength Control Unit with the lasing of the pump laser(s). It receives an Arm signal from the Master Control Unit which provides the reference, and outputs the required control signals (synchr) to the French Wavelength Control Unit. The Arm signal initiates a gate (Fig. A7) whose duration is adjusted to end approximately 500 microseconds after the last or off-line laser has lased. The trailing edge of this gate enables a 1 M Hz crystal controlled programmable counter which together with a divided by two D flip flop generates a square wave with a period 7.024 ms when the firing rate is 1 or 5 Hz, or 6.896 ms when the firing rate is 10 Hz. Each of these output periods remain

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Figure A6. Photograph of the NASA Wavelength Control Interface Unit.



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Figure A7. Wavelength Control Interface Timing.

low (logic 0) during their first half of their period following the end of the Gate pulse then go high (logic 1) producing the START of the Reticon video. The precise period was selected for the indicated firing rate to insure that this "synchr" pulse was always low at the start of a lase sequence (in other words, the Reticon was not part way through a "scan" during a lase).

Energy Monitoring System

The Electra-DIAL Z-80 microprocessor based Energy Monitoring System is capable of measuring six channels of transmitted energies, averaging a pre-selected number of shots, displaying the results and routing this data to the central computer for recording on magnetic tape. Details of the Z-80 programming and combinational block diagrams are contained in reference 8.

The complete system consists of six power sensing heads, a six-channel Power Integrator unit, a six-channel digital display unit, and a CPU chassis with associated RAM and ROM memories. Each of these will be discussed individually.

A. Power Sensing Heads

The power sensing heads contain a beam splitter, narrow band and neutral density filters, diffusers and a fast photodiode. The beam splitters are placed near Brewster's angle relative to the parallel polarized component of the laser beam in order to extract a minimum amount of energy. The reflected beam is directed through a narrow band filter when measuring fixed wavelength energies (532 nm and 1064 nm) in order to minimize the effects of flashlamp and other stray light, neutral density filters as required to reduce the beam to a useable level, and diffusers to minimize the effects of

hot spots within the laser beam. A HP 4203 fast photodiode is used for detecting visible and near IR wavelengths, and a UTC Pin 10 is used for detecting UV wavelengths. A triax cable and BNC grounded at the Integrator chassis minimize EMI pick-up.

B. Power Integrator Chassis (Drawing 1477-16, sheets 1 and 2)

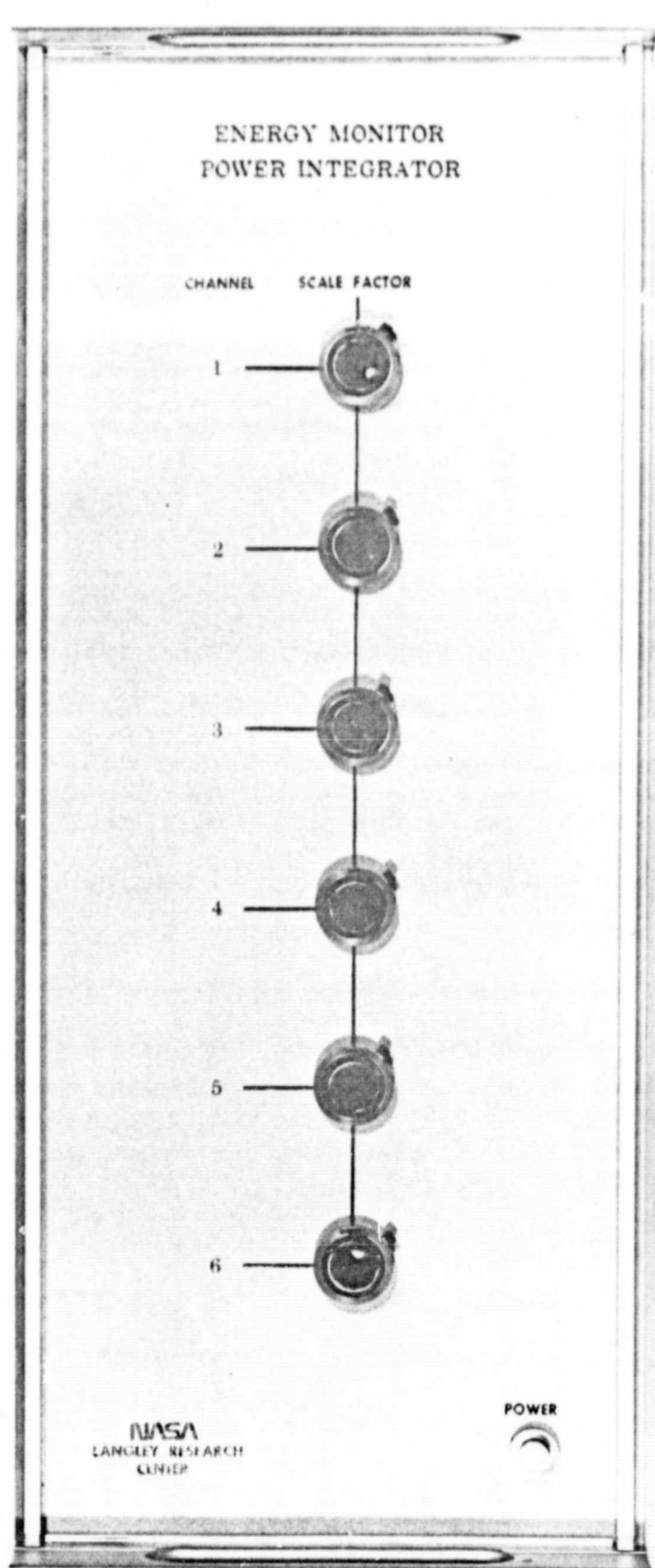
This chassis (Fig. A8) integrates the power envelope from each of the six sensors as a function time to produce energy, senses and holds the peak of the integrated waveform, and converts each of the six energies to a digital equivalent for routing to the Energy Display and CPU chassis. A high quality capacitor integrates the power envelope which reaches a peak approximately 1 microsecond after lase. The Sample-and-hold amplifier tracks this waveform and will "hold" the peak value following transients but prior to the time the waveform starts to "droop." Associated logic with adjustable timing allows the selection of this "hold" point.

A 13-bit analog-to-digital converter produces counts proportional to the energy for routing to the Energy Display chassis, and 2s-compliment binary for routing to the CPU chassis. A single 1 M Hz clock is used by all six of the A to D converters.

C. Energy Display Chassis (Drawing 1477-24)

This chassis (Fig. A9) has six display units that indicate each of the energies in millijoules. Counts from the A to D Converter within the Integrator chassis is accumulated and displayed following each lase when the averaging switch is in the "1" position, or following each 10-lases when the switch is in the "10" position. All displays are frozen until new data is available allowing the energies to be read between shots. This display is

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Figure A8. Photograph of the Power Integrator (Part of the Energy Monitoring System).

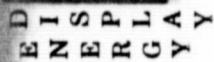


Figure A9. Photograph of the Energy Display Chassis.

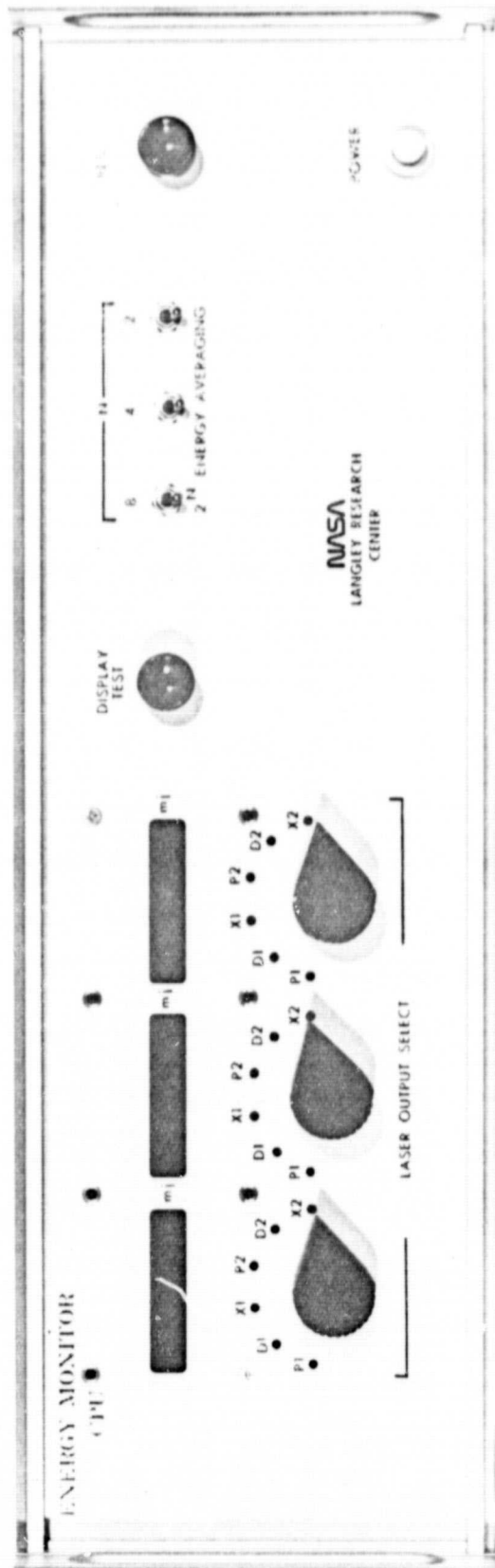
observed during optics alignment procedures for maximum energies, and during the experiments for monitoring energy trends.

D. CPU Chassis (Drawings 1477-17)

This chassis (Fig. A10) contains a Z-80 central processing unit (CPU), two 2048x8 Programmable ROMs, four 1024x4 RAMs, parallel ports and decoders, and associated logic. It uses a 4 M Hz clock and has been designed to average up to 16 K shots. It has three selectable displays for indicating the energies in millijoules. It is designed to communicate with a PDP 11/34 minicomputer through its DR11-C parallel interface module.* (See Appendix F of reference 8.) It also included an input for processing PMT gain selections on the front panel of the PMT Gain Function Generator.

Future plans are to program this Z-80 based microcomputer to perform trend analyses for failure prediction and fault isolation. The operator could be alerted if the average energy over N shots started to decrease. If this decrease was experienced at all sensing points, a message could be outputted through the main computer that the Pump laser is at fault. If the decrease was experienced at the dye output but not at the 532 nm pump output, a message would indicate that the dye laser is at fault. This possibly could be further extended depending upon the location of the sensing points.

*A second main-computer interface was added which allowed operation of this energy monitoring system without the need of this CPU chassis resulting in a reduction in overall weight. However, this puts an added burden on the main computer and produces energy readings of a lower accuracy. This was accomplished by adding a cable from the inputs of the A to D converters in the Integrator chassis to six A to D converters within the main computer. These analog energy signals are then digitized and processed within the main computer.



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Figure A10. Photograph of the Central Processing Unit (CPU) Chassis (Part of the Energy Monitoring System).

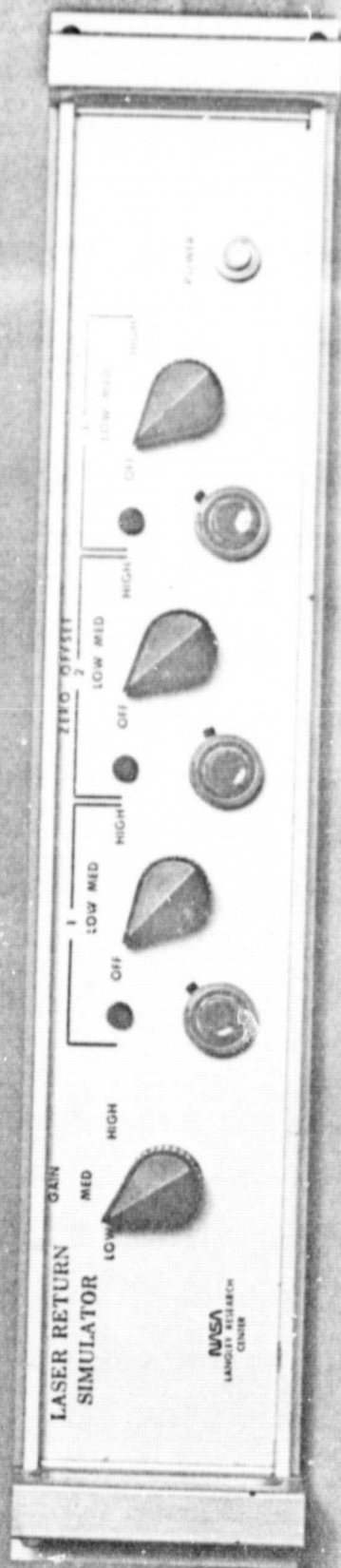
Laser Return Simulator (Drawing 1477-21)

This chassis (Fig. A11) is designed to produce an exponential decaying pulse of light simulating an $1/R^2$ laser return combined with a small amplitude steady light simulating atmospheric background noise. These light signals are inputted to the face of the PMTs or Avalanche photodiode through light emitting diodes (LEDs) placed in the view of the detector but out of the path of the return signals.

Three separate Calibration Commands (CC) inputs are installed on this Return Simulator, however, they are all tied together and terminated into 50 ohms. This allows the later addition of three separate adjustable gain $1/R^2$ channels with minor modifications should the need arise. The background noise is produced immediately upon receiving a CC followed 0.2 microseconds later with the signal return. This slight delay insures that the LED is above threshold prior to receiving the larger amplitude return signal thereby minimizing transients. The background levels can be adjusted individually for channels 1, 2 and 3 to produce LOW, MEDIUM or HIGH outputs to three different detectors.

Three ranges (LOW, MEDIUM or HIGH) are front panel selectable for the signal returns which are produced by discharging a 25 microsecond step pulse through a tantalum capacitor and selected resistors. This $1/R^2$ signal is then summed with each of the three previously described background levels to produce a 25 microsecond exponentially decaying pulse riding on a 45 microsecond uniform low-amplitude background level.

The LED can be changed to a type 4850 for simulating a visible return or a type 4950 for simulating a UV return.



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Figure A11. Photograph of the Laser Return Simulator.

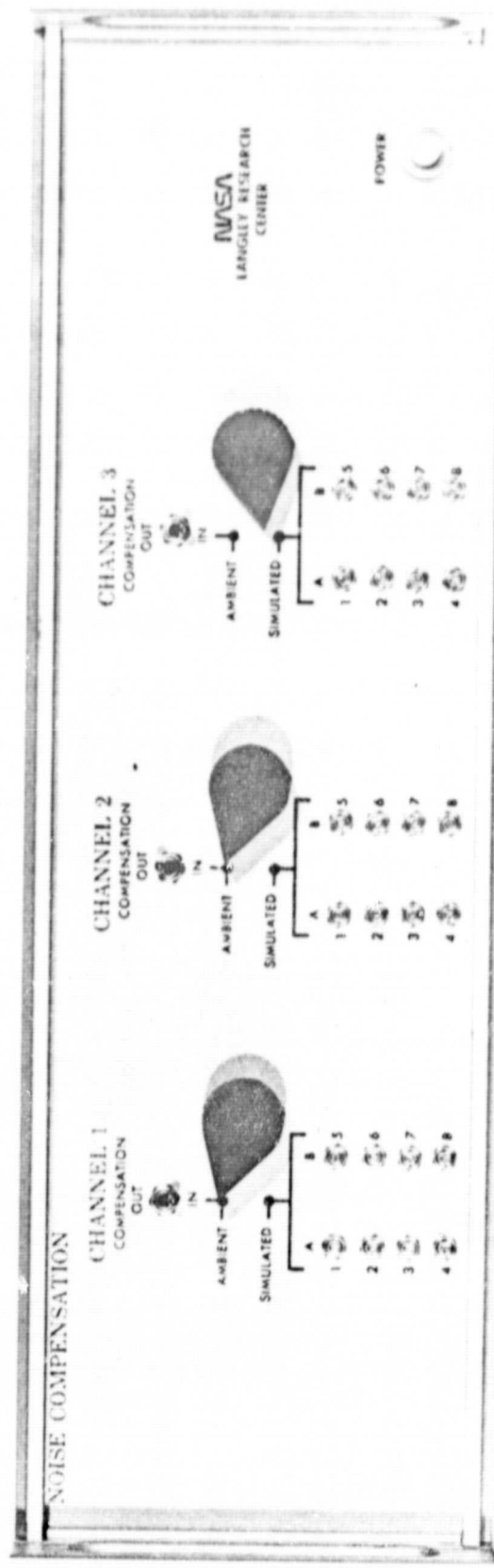
Noise Compensation System (Drawing 1477-15 and reference 9)*

The purpose of this Background Noise Compensation system (Fig. A12) is to remove the noise offset from the lidar signal plus noise return leaving primarily the signal for processing. This allows the use of lower transient digitizer range resulting in increased signal resolution.

Two different modes of noise compensation are selectable from front panel controls: (1) simulated mode, and (2) ambient mode. In the simulated mode, noise analogs proportional to those observed for the ON- and OFF-LINE gains are manually selected. Following Sequence Control (SC) pulse 3 (Table A1), the selected analog of the ON-LINE noise is subtracted from the received ambient background noise and the difference is digitized and recorded on magnetic tape. This value should be zero if the manually preselected simulated noise is equal to that measured at the time of the atmospheric observation. If it is not, this can be later corrected during data reduction. This same process is repeated following SC4 for the OFF-LINE noise. Following SC5 and SC6 (lase), the manually preselected simulated noise signal is automatically subtracted from the signal plus noise and the difference recorded.

In the ambient mode, an analog of the observed ON- and OFF-LINE background noise are stored following SC1 and SC2 respectively. These stored values are then subtracted following SC3 and SC4 from again observed background noise and the difference (if any) stored. Usually this difference will be zero unless flying over clouds with widely varying reflected sunlight. The values stored following SC1 and SC2 are then subtracted following SC5 and SC6 (lase) from the signal plus noise to produce signal only for

*The Noise Compensation System is not being used at present pending completion of the PMT base network development program aimed at improving the return signal measurement accuracy.



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Figure A12. Photograph of the Noise Compensation System.

digitizing and storing on magnetic tape. This technique will provide automatic compensation even if two or more PMT step gains are used during an ON- and OFF-LINE return or if the ON- OFF-LINE gains are different.

Video Filters (Drawing 1477-7 and reference 10)

Four duplicate passive linear phase Bessel polynomial 5-pole filters are packaged within a single chassis (Fig. A13). Each has five sections with the constant-time-delay bands (similar to cut off frequency as used with other filters - see reference 10) selectable as follows: 0.2, 0.5, 1, 2, 5 M Hz and infinity (out of circuit). These video filters were designed for Lidar applications using 50-ohm terminations, and are used primarily during ground operations for single-lase observations when the ambient background noise is high. During a mission when several returns are averaged, random noise is reduced considerable and these filters are not required.

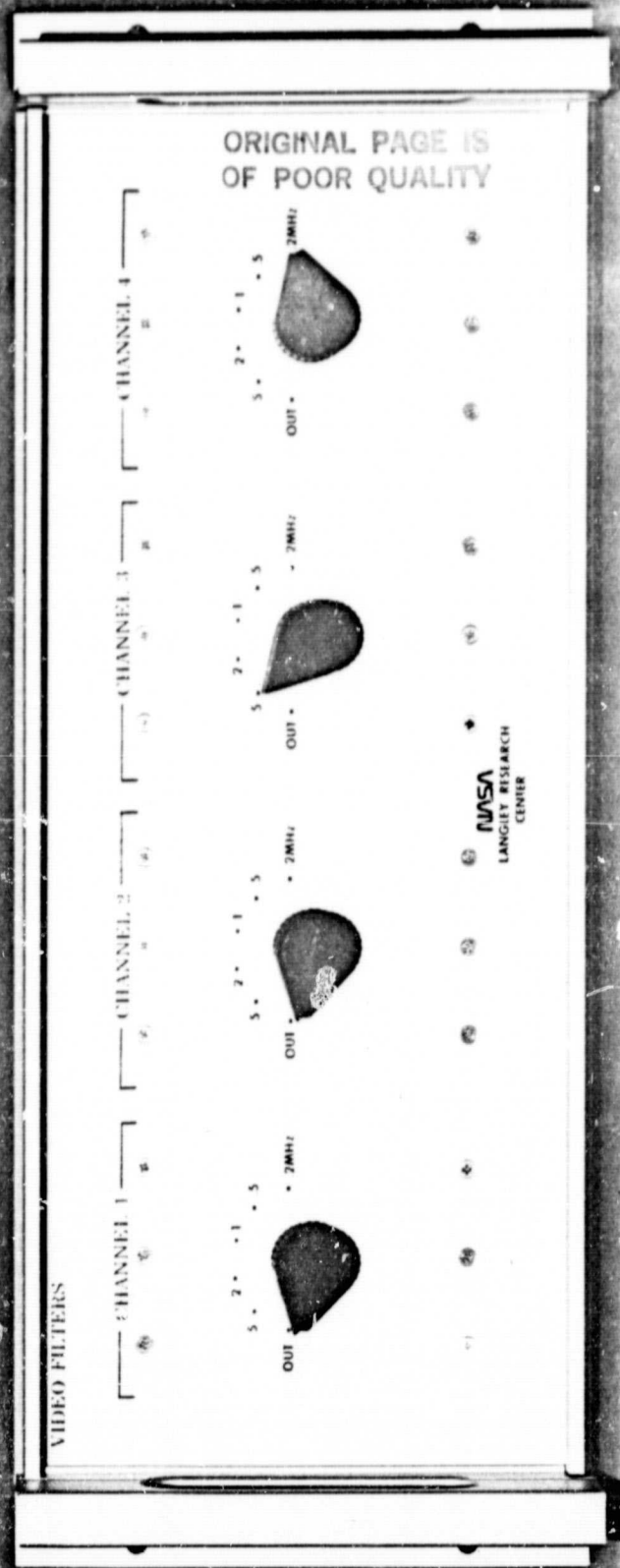


Figure A13. Photograph of the Video Filters.